

# Fiber Reinforced Polymer Bridge Deck Panels

by

Pagona Peggy Kontopanos

B.S. Civil Engineering, 2000

Polytechnic University, Brooklyn, New York

Submitted to the Department of Civil and Environmental Engineering  
In Partial Fulfillment of the Requirements for the Degree of  
Master of Engineering in Civil and Environmental Engineering

at the

Massachusetts Institute of Technology

June 2001

©2001 Pagona Peggy Kontopanos  
All rights reserved

The author hereby grants to the Massachusetts Institute of Technology the permission to reproduce and to distribute publicly paper and electronic copies of this thesis document in whole or in part.

Signature of Author\_

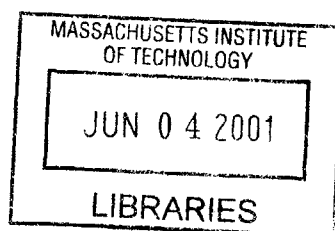
\_\_\_\_\_  
Pagona Peggy Kontopanos  
Department of Civil and Environmental Engineering  
May 18, 2001

Certified by\_\_\_\_\_

\_\_\_\_\_  
Jerome J. Connor  
Professor of Civil and Environmental Engineering  
Thesis Advisor

Accepted by\_\_\_\_\_

\_\_\_\_\_  
Oral Buyukozturk  
Chairman, Departmental Committee on Graduate Studies



BARKER

# Fiber Reinforced Polymer Bridge Deck Panels

by

Pagona Peggy Kontopanos

Submitted to the Department of Civil and Environmental Engineering  
on May 18, 2001 in partial fulfillment of the  
requirements for the Degree of Master of Engineering in  
Civil and Environmental Engineering

## Abstract

The United States is currently facing the challenge of meeting its growing infrastructure rehabilitation needs with the limited funding that is available. There has been a great deal of research performed to identify innovative materials that can be used to provide cost effective, durable and sustainable solutions to this problem. One of the largest areas of infrastructure in need of investment is bridge rehabilitation and replacement. As a result of aging, poor maintenance, corrosion, inadequate design or increased loadings, over 30% of the U.S.'s bridges have been classified as structurally deficient or functionally obsolete. A significant portion of these deficiencies can be attributed to the substandard condition of the bridge decks.

The focus of this investigation was to determine the viability of using fiber reinforced polymer (FRP) composite materials to produce an effective alternative for the replacement and rehabilitation of vehicular bridge decks. To make an assessment of the potential of this innovative material, a study was carried out covering the FRP bridge deck design and manufacturing processes, the completed projects, the experiences of the parties involved with these projects and the future plans to improve this technology.

The results of this study showed that the widespread success of FRP bridge decks is limited by the high initial cost and the uncertainty of the technology. In order for FRP to become competitive with conventional materials, its costs must be driven down by streamlining the design and manufacturing processes. In addition, further research must be conducted so that design, installation and construction specifications and a design code can be developed. If feasible methods of overcoming these hindrances can be found, FRP bridge decks may be able to anchor themselves as a mainstay in the U.S. infrastructure industry.

Thesis Supervisor: Jerome J. Connor

Title: Professor of Civil and Environmental Engineering

## Table of Contents

<b>Section 1 – Introduction</b>	<b>6</b>
1.1 The Need for Innovative Decking Materials	6
1.2 Introduction to Composite Materials	7
1.3 Fiber Reinforced Polymer Composites	8
1.4 FRP Manufacture	11
<b>Section 2 – Development of the FRP Bridge Deck Industry</b>	<b>15</b>
2.1 History and Development of the Composite Industry	15
2.2 The Benefits of Using FRP for Bridge Decks	16
2.3 The Drawbacks of Using FRP for Bridge Decks	17
<b>Section 3 – Current State of the FRP Industry</b>	<b>20</b>
3.1 The IBRC Federal Grant Program	20
3.2 FRP Bridge Deck Systems	21
3.2.1 3TEX, Inc.	21
3.2.2 Creative Pultrusions, Inc.	25
3.2.3 Hardcore Composites	27
3.2.4 Kansas Structural Composites	29
3.2.5 Martin Marrieta Composites	31
3.3 The Manufacturers’ Major Selling Points for FRP Bridge Decks	34
<b>Section 4 – Advancements and Applications of FRP in the U.S.</b>	<b>37</b>
4.1 Case Study #1 – Ohio Department of Transportation	37
4.2 Case Study #2 – New York State Department of Transportation	46
4.3 The DOTs’ Standpoint on the Viability of this New Technology	52
4.4 Steps the Manufacturers are Taking to Address the Needs of the DOTs	54
<b>Section 5 – Future of the FRP Bridge Deck Industry</b>	<b>57</b>
<b>Appendix A – Salem Avenue Bridge Deck Replacement Design Drawings</b>	
<b>Appendix B – Bennetts Creek Bridge Deck Replacement Design Drawings</b>	
<b>Appendix C – Comparison of Different Deck Systems</b>	
<b>Appendix D - References</b>	

## List of Figures

Figure 1 – The constituents of a composite material	8
Figure 2 – Schematic of pultrusion FRP fabrication process	12
Figure 3 – Schematic of resin transfer molding FRP fabrication process	13
Figure 4 – Schematic of VARTM FRP fabrication process	13
Figure 5 – U.S. 2000 Composite Market Share Volume	16
Figure 6 – 3TEX, Inc. TYCOR™ FRP Bridge Deck Panel	22
Figure 7 – Schematic of 3TEX, Inc. FRP bridge deck installation details	23
Figure 8 – TYCOR™ FRP deck system connection details	24
Figure 9 – Detail of TYCOR™ FRP deck system joint seal	24
Figure 10 – Superdeck™ FRP bridge deck system DT & HX sections	25
Figure 11 – Detail for Superdeck™ panel shear stud connection to steel girders	26
Figure 12 - Superdeck™ demonstration project in West Virginia	27
Figure 13 – Cut-away view of the Cellular Core Honeycomb	28
Figure 14 – FRP deck through bolted to truss floor beams	29
Figure 15 – Cut-away of splice plate to transfer shear and moment	30
Figure 16 – Kansas Structural Composites FRP honeycomb sandwich panel	30
Figure 17 – Installation of Kansas Structural Composites FRP deck panel	30
Figure 18 – Kansas Structural Composites FRP deck typical connection detail	31
Figure 19 – Photo of exhibit demonstrating strength of MMC bridge deck	32
Figure 20 – Typical MMC Duraspan™ bridge deck section	33
Figure 21 – Photos from load cycling tests performed on Duraspan™ deck	33
Figure 22- Typical Duraspan™ bridge deck connection details	34
Figure 23 – Photo of the Salem Avenue Bridge prior to deck replacement	37
Figure 24 – Photo of crack in the concrete wearing surface	42
Figure 25 – Deck-to-girder connection	43
Figure 26 – Cracks in polymer wearing surface at a deck joint	44
Figure 27 – Joint between the HCI and CPI deck panels	45
Figure 28 – Deteriorated superstructure of the Bennetts Creek Bridge	47
Figure 29 – Photo of Bennetts Creek Bridge replacement road surface	48
Figure 30 – Placement of first half of the superstructure	49



Figure 31 – Completed Bennetts Creek FRP Bridge deck	50
Figure 32 – Load testing of the FRP superstructure	51

### **List of Tables**

Table 1 – Typical Properties for Composite Matrix Materials	9
Table 2 – Typical Fiber Properties	10

## **Section 1 – Introduction**

### **1.1 The Need for Innovative Decking Materials**

The value of the U.S.'s transportation infrastructure in 1996 was estimated at \$2.5 trillion. Approximately \$120 billion is spent per year on transportation related construction, \$100 billion of which is spent on maintenance. The current deficient state of our nation's infrastructure creates an additional \$48 billion in traffic congestion delays and wasted fuel per year. Our nation currently faces the challenge of restoring the deteriorating infrastructure, with continually expanding needs coupled with the increasingly tight federal and state budgets. A great deal of research has been done to identify innovative materials and methods to meet the growing needs of the nation's infrastructure. Some of the innovative solutions that have been investigated are epoxy coated rebar, high performance concrete, stainless steel reinforcement and composite materials.

Of particular interest in this paper are the proposed composite material solutions. Many different composite material applications, have been proposed by the composite industry in response to the infrastructure industry's identified needs. Some of the different composite applications that have been demonstrated include composite reinforcement for concrete; systems for strengthening/seismic retrofit of existing steel, concrete and wood structures; dowel bars for concrete highway pavements; new structural shapes; vehicular and pedestrian bridge systems; and bridge decks. This is a part of the composite industry's attempt to expand into applications in construction from their more traditional markets in the automotive and aerospace industries. The rehabilitation of the U.S.'s highway system presents an enormous potential market for composites well into the 21<sup>st</sup> Century. To take advantage of this unprecedented opportunity, the composites industry must work to overcome the resistance and cautiousness of the construction industry to this new and uncertain technology.

One of the largest areas of infrastructure in need of investment is bridge rehabilitation and replacement. The majority of the nation's 580,000 bridges were built in the 1950's and 60's and as a result of aging, poor maintenance, corrosion, inadequate design or increased loading, over 30% of these bridges have been classified as structurally deficient or functionally obsolete. Structurally deficient means that the bridge is closed or load restricted due to its deteriorated structure, while functionally obsolete means that the bridge cannot service the type or volume of traffic it is subjected to. .

The focus of this investigation will be the viability of using fiber reinforced polymer (FRP) composite materials to produce an effective alternative for the rehabilitation and replacement of vehicular bridge decks. A significant portion of the deficiencies in bridges is due to the substandard condition of the bridge deck. The main problems found with the existing bridge decks are the extensive corrosion in the concrete and steel due to the environment and the deicing salts and the need for increased live load capacity. The conventional concrete/steel deck systems that are most frequently used do not provide the long term durability and sustainability that is needed. The superior strength and durability characteristics of FRP bridge decks offer a promising alternative to the conventional systems, which may better meet the long-term goals of the federal government

To make an assessment of the true potential of this innovative material, this paper studies the FRP bridge deck design and manufacturing process, the completed projects, the experiences of the parties involved with these projects and future plans to improve this technology. An important first step in this investigation is to get an understanding of the basics of composite materials and technology, which is given below.

## 1.2 Introduction to Composite Materials

A structural composite combines two distinct materials on a macroscopic scale to produce a material whose performance and properties are superior to those of the constituent materials. One of the constituent materials acts as the reinforcement and is

generally discontinuous with high stiffness and strength. The other material acts as the matrix and is generally continuous in nature with relatively lower stiffness and strength. An interphase is usually created between the two materials due to the chemical reactions and the other processing effects. The chemical makeup, geometry and distribution of these three elements of the material, produce the unique properties of the composite.

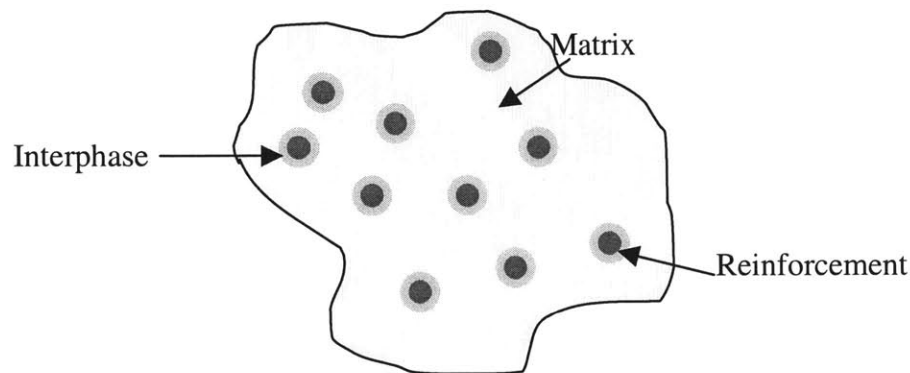


Figure 1 – The constituents of a composite material.

### 1.3 Fiber Reinforced Polymer Composites

The focus of this study is Fiber Reinforced Polymer (FRP) composites. FRP are a class of composite materials that are characterized by a thermoset or thermoplastic polymer matrix, combined with fibers or any other reinforcing material. FRP composites are anisotropic and thus their properties are directional, with their best mechanical properties being demonstrated in the direction of the fiber placement. This anisotropy sets the FRP apart from more conventional materials such as steel and concrete, which are isotropic and have uniform properties in all directions.

The advantages of FRP composite materials over conventional materials are their high specific strength, high specific stiffness, long fatigue life, low density and adaptability. These characteristics make composites desirable for applications that require improved corrosion resistance, wear resistance, appearance, thermal stability, thermal insulation, thermal conductivity and acoustic insulation.

The polymer or resin greatly influence the physical properties of the composite material. Its main functions are to hold the composite together, to protect the fibers from mechanical and environmental damage and to transfer the stress between the fibers. The most frequently used thermosetting resins include unsaturated polyesters, epoxies, vinyl esters and phenolics. Typical properties for some of these materials are given in the table below. Of these resins, unsaturated polyesters make-up approximately 75% of the resins used for polymer matrix composites. The advantages unsaturated polyester offers include a good balance of chemical, mechanical and electrical properties, dimensional stability, lower cost and ease of handling. Epoxy resins are generally used in the manufacture of high-performance composites, which require superior mechanical and electrical properties, resistance to corrosion and environmental forces, good adhesion to a substrate or stability at high temperatures. Vinyl-ester resins were created as a hybrid that combines the benefits of unsaturated polyester resins with those of epoxy resins. The resulting material offers improved mechanical toughness and excellent corrosion resistance combined with better handling and faster curing time.

Material	$\gamma$	Tensile Strength (MPa)	Modulus of Elasticity (GPa)	Coeff. Of Linear Exp. ( $10^{-6}^{\circ}\text{C}^{-1}$ )
Polyester	1.28	45-90	2.5-4.0	100-110
Vinylester	1.07	90	4.0	80
Epoxy	1.03	90-110	3.5-7.0	45-65
Phenolic	1.6	45-59	5.5-8.3	30-45

Table 1 – Typical Properties for Composite Matrix Materials

(Adapted from Composite Materials & Structures in Civil Engineering)

The function of the fibers is to provide the strength and stiffness needed to carry the applied load. To meet the performance requirements of the composite, the fibers chosen should have a high modulus of elasticity, high ultimate strength, uniformity and stability of strength, and high uniformity in diameter. Reinforcing fibers can be made either from man-made materials or natural materials, but the majority of commercially used fibers are man-made. Some of the most frequently used reinforcing materials include glass fibers,

carbon fibers, aramid fibers, polyethylene, polypropylene, polyester and nylon. Typical properties of some of these materials are given in Table 2. E-glass fibers are the predominantly used reinforcement in polymer matrix composites due to their good electrical insulating properties, low susceptibility to moisture and good mechanical properties. Glass fibers used for composite reinforcement generally have a diameter of 0.00035 to 0.00090 inches. Carbon fibers offer an excellent combination of strength, low weight and high modulus but are not as frequently used as glass fibers due to their higher cost. Aramid fibers have reasonably high tensile strength, a medium modulus and a very low density as compared to glass or carbon and have the added benefit of high damage/impact resistance. Fiber reinforcement is available in many different forms including multi-end and single-end rovings, reinforcing mats, woven, stitched and braided fabrics, 3-D fabrics, tapes and tows.

Material	Elastic Modulus (GPa)	Tensile Strength (MPa)	Ultimate Strain (%)
Glass	55-81	2.8-4.1	3-4.8
Carbon	170-310	1.4-6.8	1.3-2.0
7u Aramid	62-83	2.8	3.6-4.0
Polyethylene	117	2.6	3.5

Table 2 – Typical Fiber Properties

(Adapted from Adv. Composites for Bridge Infrastructure Renewal)

In addition to these two main constituents of the composite material, fillers and additives are often combined into the mix to further improve the performance of the material. Inorganic fillers are added because they reduce the cost of the material and enhance the performance of the composite. The enhancements to the composite are in the form of reduced shrinkage, improved fire resistance, improved mechanical strength, enhanced laminate uniformity and increased crack resistance. The most frequently used fillers include calcium carbonate, kaolin (clay), and alumina trihydrate.

Additives are frequently included in the composite blend because they can modify the properties of the material to meet the specific performance requirements of the

application. Properties that are often achieved through the inclusion of additives/modifiers include fire resistance, improved air-release capabilities, emission control, viscosity control, electrical conductivity and improved toughness. Specific additives are used because they improve the processability of the resin matrix during fabrication. This class of additives includes antioxidants, foaming agents, plasticizers, antistatic agents, slip and blocking agents, heat stabilizers and ultraviolet stabilizers. Other additives may be added to act as a catalyst or inhibitor during mixing, to provide a specific color in the final product or to facilitate the removal of the product from molds.

#### 1.4 FRP Manufacture

The manufacturing process used for fabrication also plays a large part in shaping a FRP composite material's properties. There are many manufacturing processes utilized and each of them has its particular advantages and disadvantages. The different manufacturing processes result in varying degrees of compaction, degrees of curing and variations in the microstructure and initial internal stresses. In order to select the approach that best meets their production needs, the manufacturing team must make an evaluation of their particular product, its performance requirements, cost limitations and the available equipment, materials and labor. The most widely used manufacturing processes include pultrusion, resin transfer molding (RTM), vacuum assisted resin transfer molding (VARTM), hand lay-up and compression molding. An overview of each of these manufacturing processes is given below.

Pultrusion is a continuous open-molding process that is used to combine fibers and thermosetting resin. This automated process is used to produce elements of uniform cross section, which are continuously pulled through the pultrusion machine and cut at the desired length. The process starts with the reinforcing materials being positioned at a specified location using guides and being pulled through a resin bath where they are coated with a liquid thermosetting resin. These resin-covered reinforcements are then drawn through a heated metal pultrusion die, which is shaped in the form of the final product. The heat in this metal die activates the curing of the resin, changing it from its

liquid to solid form. The laminate is then cooled down to its final solid state and pulled through the pultrusion machine to be cut to the desired length. The benefits of this process are that it allows for a flexible design, optimized fiber architectures and reduced painting requirements.

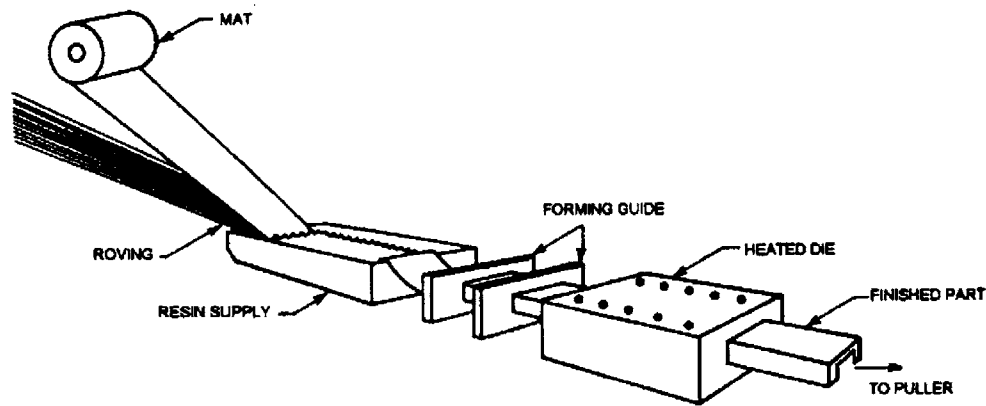


Figure 2 – Schematic of pultrusion FRP fabrication process.

Resin transfer molding (RTM) is a “closed mold process.” The reinforcing material is enclosed between a male and a female mold surface and resin is then injected into the mold cavity to saturate the reinforcement and fill all the voids within the mold set. The composite is then typically cured with heat. The benefits of this process include lower emissions in comparison to the open mold process, production of a high-quality finish, relatively fast manufacture, production of tighter dimensional tolerances, and the ability to produce complex mold shapes. Some disadvantages of this manufacturing process include the high tooling costs and the limitations placed on product sizes because of the use of a mold.



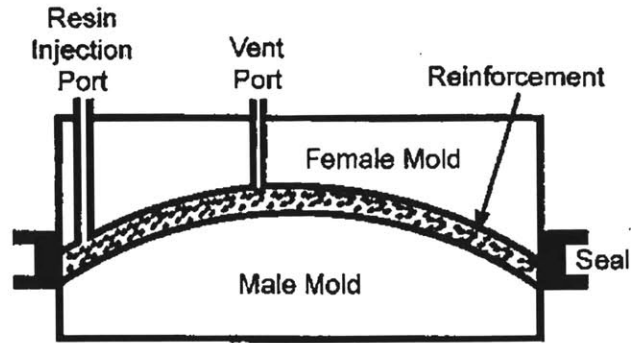


Figure 3 – Schematic of resin transfer molding FRP fabrication process.

Vacuum assisted resin transfer molding (VARTM) is a variation of RTM that produces composites by placing the reinforcements into a mold, applying a vacuum bag to the open surface, and pulling the vacuum while at the same time infusing the resin to saturate the fibers. The benefits of this process are that it produces a composite that is virtually void-free and allows for visual monitoring of the fiber saturation to ensure the product is of high quality.

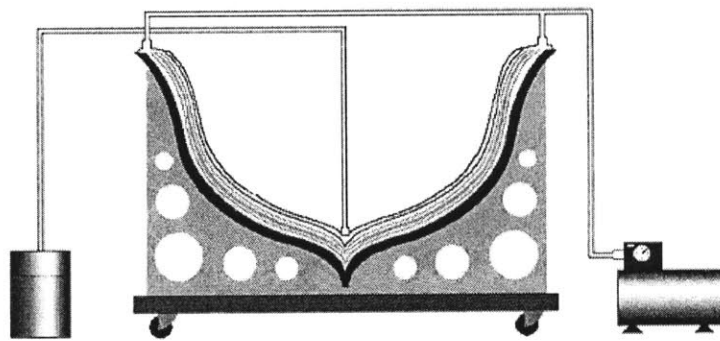


Figure 4 – Schematic of VARTM FRP fabrication process.

Hand lay-up is the oldest and simplest method of producing reinforced plastic laminates. The most frequently used hand lay-up process is the wet lay-up process. This process begins with the placement of the resin in a mold either through spraying or brushing. The reinforcement is then saturated with resin and placed into the mold after which it is compacted to remove any entrapped air. This manufacturing process is relatively cost

efficient because it does not require the purchase of expensive equipment, but it is the least automated and most labor-intensive method.

Compression molding is the most common method of molding thermosetting materials. This process begins with the placement of the uncured composite mix, containing a temperature-activated catalyst into the mold. The mold is then closed and subjected to heat and pressure so that the resin-reinforcement blend flows to fill the mold cavity and the mixture cures.

## **Section 2 - Development of FRP Bridge Deck Industry**

### 2.1 History and development of the composite industry

The use of composite materials dates many centuries back, with one of the earliest examples being clay bricks reinforced with straw in ancient Egypt. Composite technology continually progressed over the years into uses such as iron rod reinforcement in masonry bricks in the 19<sup>th</sup> century and fiber reinforcement in polymers (FRP) in the 20<sup>th</sup> century. The first recorded use of a FRP composite material was in the manufacture of an experimental boat hull in the 1930's. Widespread use of FRP composites began in the early 1940's, primarily in the defense industry during World War II. In particular, glass FRP was used in the manufacture of military aircraft and ships due to its high strength-to-weight ratio and its high resistance to weathering and corrosion. Although military applications no longer hold the largest market share, the military still uses FRP due to its nonmagnetic nature. In the late 1940's, the benefits of this composite material were realized by the oil industry and FRP was used to manufacture pipes with superior durability and strength. In the 1950's uses of FRP emerged in equipment for the chemical processing, pulp and paper, power, waste treatment and metal refining industries. FRP technology continually advanced and revolutionized industries such as the marine industry in the 1960's and the automotive industry in the 1970's. In the late 1970's and 1980's a great deal of research was done in Europe and Asia into different types of composite reinforcing products. The first highway bridge using composite reinforcing tendons was built in Germany in 1986 and the first all composite pedestrian bridge was built in Scotland in 1992. In 1996, the U.S. installed its first FRP reinforced concrete bridge deck in McKinleyville, West Virginia and its first all-composite vehicular bridge deck in Russell, Kansas.

Below, the pie graph shows the distribution of the \$9 billion composite industry in the United States in 1998.

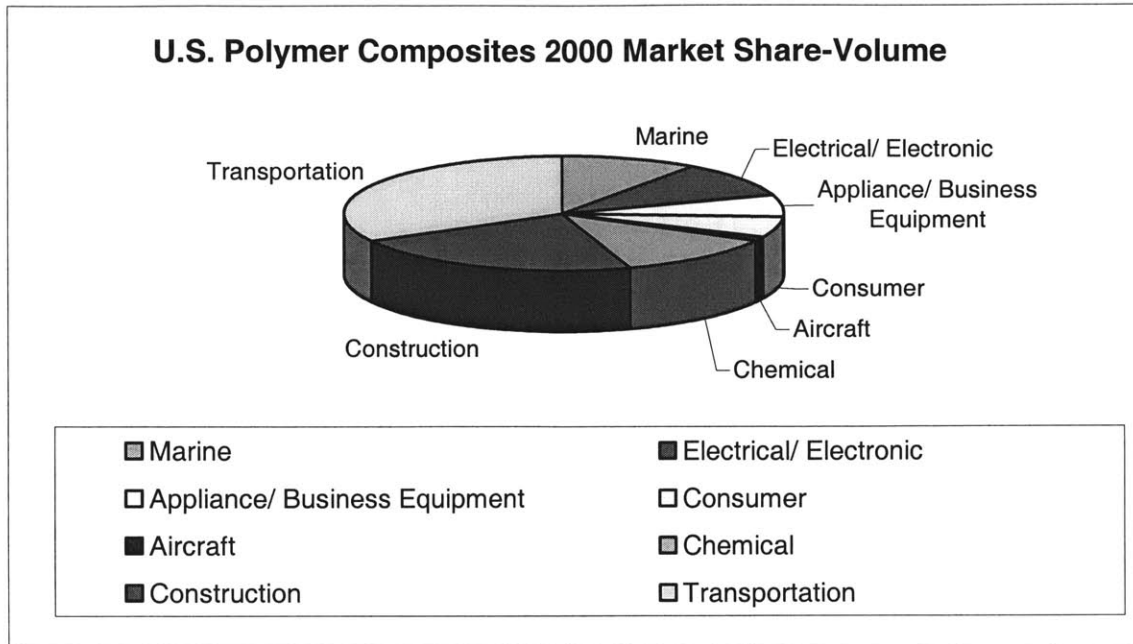


Figure 5 - U.S. 2000 Composite Market Share Volume

(Adapted from "The Composites Market")

FRP composites have an enormous potential market in civil infrastructure because they offer many benefits in structural applications due to their lightweight, superior corrosion and weathering resistance, enhanced durability and fatigue characteristics, the flexibility of their design and properties and reduced maintenance requirements.

## 2.2 The Benefits of Using FRP for Bridge Decks

FRP composites exhibit many qualities that make them an attractive material for vehicular bridge decks. Their properties can be tailored to meet the specific performance needs of the particular bridge project. The mechanical properties and the performance of the material are governed by the type, orientation and density of the fibers, the type of polymer system used and the manufacturing system implemented to fabricate it. By manipulating these different elements, many benefits can be obtained for bridge deck applications, including:

- Corrosion & Weather resistance - One of the major causes of bridge deck deterioration is the corrosion of the reinforcing steel due to exposure to moisture

and the use of de-icing salts. FRP has a higher resistance to these effects and does not contain metal reinforcement that will deteriorate and rust when exposed to the elements. An additional benefit is that the FRP deck acts as a roof to the steel superstructure, effectively shielding it from these detrimental elements. This increased durability will produce a deck with a longer service life and lower maintenance costs.

- **Lightweight** – FRP decks are approximately 1/5 the weight of comparable concrete decks. This decreased dead load allows the bridge to carry more live load and thus allows for a higher load rating. The lightweight of the panels also reduces construction and installation costs because it minimizes the need for specialized transport vehicles, construction vehicles and construction equipment. The lightweight of the deck can also be beneficial in seismic applications, since the seismic response of the structure decreases with reductions in weight.
- **High strength-to-weight ratio** - FRP composite deck has 6 to 7 times the load capacity of a reinforced concrete deck with only 20% of the weight.
- **Dimensional Stability** – FRP exhibits low thermal conductivity and low coefficient of thermal expansion.
- **Ease and speed of installation** – The construction time is reduced due to the modular nature of the bridge deck components. This is beneficial because it reduces the interruptions of service and inconvenience to the users. It also reduces the amount of labor that is needed to construct the structure.
- **High quality control** - Sections are almost completely fabricated off site at the manufacturing plant.
- **Lower life-cycle costs** – Life cycle costs include both the user and owner costs throughout the life of the structure including the costs for design, manufacture, installation, construction, maintenance, replacement and disposal.

### 2.3 The drawbacks of using FRP for bridge decks

Although FRP bridge decks do offer many promising characteristics that make them attractive alternatives to conventional decks, there are several aspects of this new

technology that are problematic. Due to the newness of FRP bridge deck technology, there are still many issues that must be addressed in order for this innovative material application to grow and find acceptance within the construction industry. The drawbacks of FRP bridge deck technology that have been identified include:

- High initial costs – Initial cost is approximately 60% higher than conventional concrete decks. This cost differential is primarily due to the high raw material and manufacturing costs.
- Unknown technology – Bridge engineers and state Departments of Transportation (DOTs) are often conservative and wary about utilizing a material that has not been thoroughly tested and still involves uncertainties.
- No codes or standards- Lack of comprehensive design methodology. The properties of FRP composites vary depending on the fiber type, fiber architecture and fiber volume fraction, and their design is much more complex than conventional materials. As a result, the existing codes and standards cannot be applied to their design and the bridge engineers must rely on the manufacturer's knowledge of the system.
- Need for design, construction and installation specifications – Due to the limited experiences that DOT's and bridge engineers have had with FRP bridge decks, sufficient studies and research have not been completed to create the needed specifications.
- Flexibility – FRP decks are more flexible than concrete decks and thus their design is stiffness driven. There may be problems with deflection limits.
- Problems with connections - FRP deck connections are either mechanical, bonded or a combination of the two. The connection designs have been primarily based on those that have been used for conventional structural materials and must be refined to account for the complex anisotropic nature of FRP materials. In addition, better installation procedures and quality control measures are needed to ensure proper connections are made in the field.
- Problems with wearing surface –The overlays used may crack or debond if they do not have stiffness, tensile strength and flexural properties comparable to the

FRP deck. In addition, care must be taken to properly prepare the surface of the FRP prior to application of the wearing surface in order to ensure there is satisfactory adhesion.

- Difficult to inspect - Since the FRP deck panels are sealed and enclosed, they are inaccessible for field inspection and thus sophisticated NDE and fiber optic sensors must be utilized.
- Low fire and temperature resistance - Composite resin systems have been found to have lower fire resistance and reduced temperature resistance in comparison to traditional materials used in infrastructure applications. The lower fire resistance is due to the organic matrix component of the FRP. If exposed to fire, there are several concerns, including the degradation of the polymer matrix strength and the toxic smoke that is emitted when the matrix is ignited. When exposed to elevated temperatures, FRP is also susceptible to the effects of creep.

## **Section 3 - Current State of the FRP Industry**

### **3.1 The IBRC Federal Grant Program**

In June 1998, The United States Congress passed the Transportation Efficiency Act for the 21<sup>st</sup> Century (TEA-21). TEA-21 authorized the funds necessary for two major initiatives that aim at improving the condition, durability and capacity of the nation's bridges. The first initiative allocates \$20.4 billion for the rehabilitation or replacement of bridges that are selected due to their deteriorated condition or reduced capacity. The second initiative is named the Technology Deployment Program, whose aim is to encourage the use of innovative materials and technologies to rehabilitate or replace bridges, or for the construction of new bridges. To meet the goals of this initiative, the Innovative Bridge Research and Construction Program (IBRC) was established. The legislated goals of the IBRC include the intent of advancing: (Listed in the TEA-21 Congressional Legislation)

- New, cost-effective, innovative material highway bridge applications.
- Reduced maintenance and lifecycle costs of bridges, including the costs of new construction, replacement or rehabilitation of deficient bridges.
- Construction techniques to increase safety and reduce construction time and traffic congestion.
- Engineering design criteria for innovative products and materials for use in highway bridges and structures.

Shortly after the passing of this legislation, a solicitation was released inviting proposals for candidate projects. Funding was allocated, on an annual basis, to projects ranging the entire innovation process including engineering, repair, construction, and post-construction monitoring and evaluation.

The exploration and advancement of FRP bridge decks in the last few years has been a direct result of the IBRC program. The majority of the FRP bridge projects that have



been or are being completed in the U.S. have been funded by this initiative. In the fiscal years of 1998-2001, approximately 50% of the projects funded by the IBRC have been FRP applications, and 35% of these have been bridge deck projects. Without the funding needed for the research and implementation of these innovative systems, the State DOT's would not be able to justify allocating money from their tight budgets to use this still unproven technology. As State DOT's are often very conservative in their design approach, an initiative such as this is necessary to encourage their participation in innovation.

### 3.2 FRP Bridge Deck Systems

Due to the emerging market for FRP bridge decks, a handful of companies have formed in the United States that design, engineer and manufacture these innovative deck systems. Each deck manufacturer has a different proven system with a unique design that has been developed to meet the needs of the market. An overview of each of the major manufacturers and the different FRP deck systems currently available is given below. (See Appendix C for a comparison of the different deck systems.)

#### 3.2.1 3TEX, Inc.

3TEX, Inc is headquartered in Cary, North Carolina and designs and manufactures a variety of composite products including blast mitigation systems, automotive and transportation vehicle components, marine, defense and recreational protective products. They have recently established a business unit to manufacture low-profile composite bridge decks for vehicular and pedestrian use.

The FRP bridge deck system 3TEX produces is the TYCOR<sup>TM</sup> and is marketed as an alternative for traditional wood or steel bridge decks. The TYCOR<sup>TM</sup> system is characterized by its patented Fiber-Reinforced Foam (FRF) core sandwich, which is reinforced in the Z-direction with fiberglass rovings and is covered with fiberglass fabric skins. The glass skins are made of a combination of 2-D knitted fabric and 3-D woven

fabric. The deck is manufactured using a proprietary VARTM process. Through this molding process, liquid resin is infused into the skin layers and into the rovings in the core, so that when the resin is cured, the glass fiber rovings in the core are converted into rigid struts. These rigid struts eliminate the possibility of the delamination of the face skins.

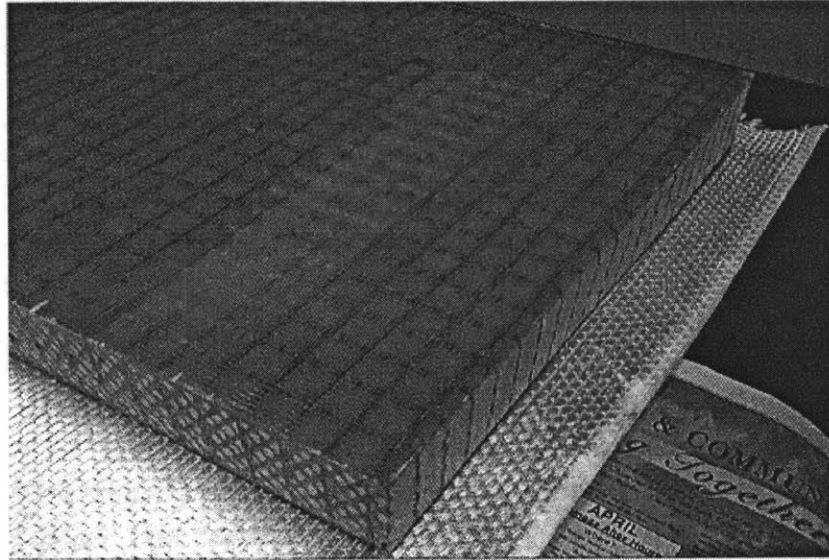


Figure 6 –3TEX, Inc. TYCOR™ FRP bridge deck panel

The deck typically has a 3.3 in nominal thickness (without wear surface) and weighs 7psf. The deck is designed for girder spacing of 2 to 3 ft. and replaces existing corrugated steel with an asphalt/concrete or wood decking. It is available in large panels in the range of 8 ft. x 30-36 ft, which is usually sufficient to span the full width of the bridge.

The TYCOR™ system is designed for AASHTO HS25 load rating and for a deflection limit up to  $L/500$ . For a clear span of 28 in, the deck exhibits ultimate strength in excess of 40 tons, which is over four times the required strength. Limited cyclic load testing has been performed on this deck system, showing positive results. The decks were loaded to 20 tons in bending for ten cycles and then loaded to failure, but still exhibited 40 tons ultimate strength. When loaded to failure, the material exhibits stable ductile failure modes. Further cyclic load testing is planned to investigate the long-term behavior of the deck when subject to weathering and the environment.

## DECK SCHEMATIC

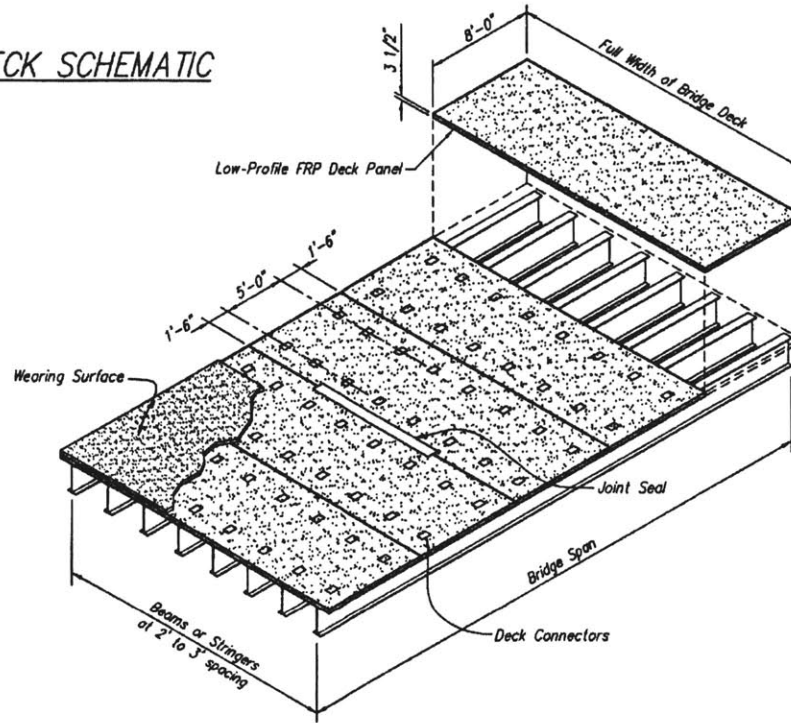
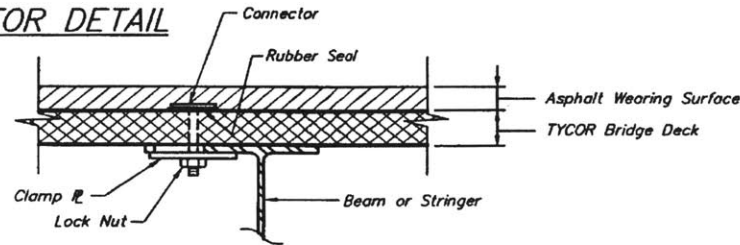


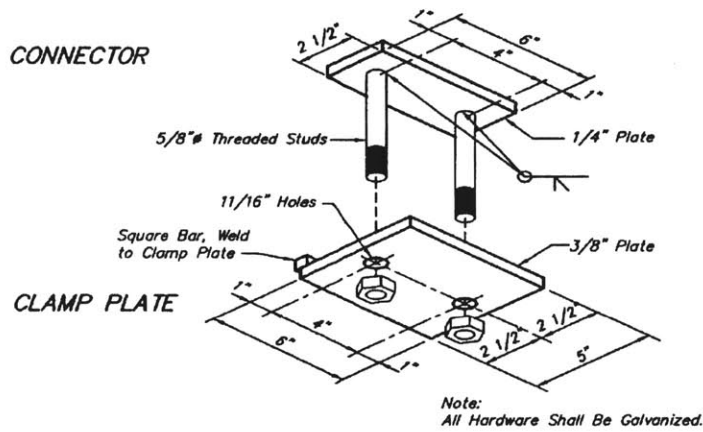
Figure 7 – Schematic of 3TEX, Inc. FRP bridge deck installation details.

The connections used for this system are non-structurally composite and the decks are simply bolted to the beam flanges, using either clamp connectors or self-drilling screw connectors, as can be seen in the figure 8. These simple connections make installation relatively quick and simple and do not require highly skilled labor to ensure satisfactory quality.

### CONNECTOR DETAIL



### CONNECTOR



### ALTERNATE CONNECTOR DETAIL

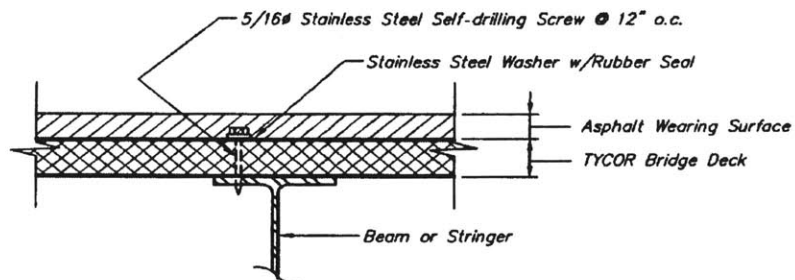


Figure 8 - TYCOR™ FRP deck system connection details.

### JOINT SEAL

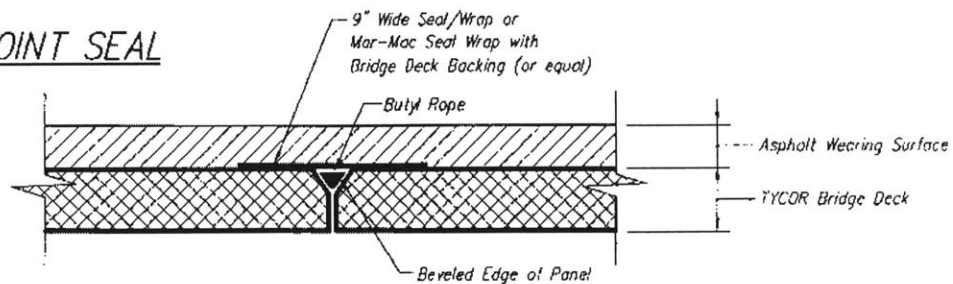


Figure 9 – Detail of TYCOR™ FRP deck system joint seal.

### 3.2.2 Creative Pultrusions, Inc.

Creative Pultrusions is headquartered in Alum Bank, Pennsylvania and has been manufacturing FRP products for construction, electrical/electronic, transportation, consumer and water/wastewater applications since 1973.

The pre-engineered FRP bridge deck system manufactured by Creative Pultrusions is Superdeck™. The Superdeck™ bridge modules are formed by bonding together pultruded double trapezoid (DT) sections and pultruded (HX) hexagonal sections (Shown in figure 10). The matrix is a weather-resistant vinyl ester resin and is reinforced with E-glass fibers in the form of multi-axial stitched fabrics, continuous roving and continuous fiber mats. The deck typically has a nominal depth of 8 in and weighs 22 psf. The deck is generally fabricated in sections equal to 8 ft. x full width of the bridge.

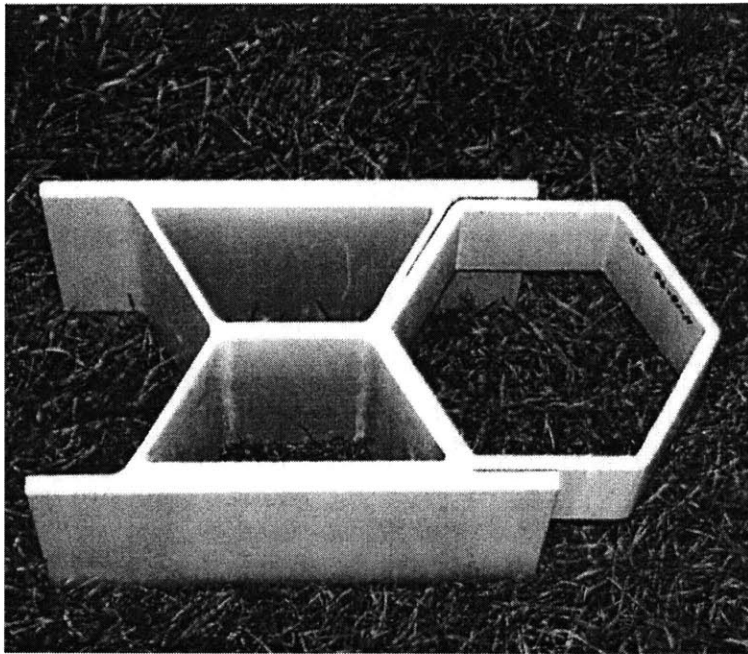


Figure 10 - Superdeck™ FRP bridge deck system DT and HX sections.

The Superdeck™ system is designed for the service, strength and fatigue limit states according to the AASHTO LRFD Bridge Design Specifications and Standard Specifications for Highway Bridges. The deck meets the AASHTO HS 25 loading

requirements and limits the deflection to  $L/500$ . The ultimate bending strength of the deck is 42 ksi and the design stress is 20 ksi. To evaluate the fatigue and fracture of the deck sections, specimens were subjected to 2 million load cycles for a load range of 2 kips to 35 kips. From the testing program, it was found that this deck system's stiffness and strength are not significantly affected by fatigue cycling, has a ductile failure mode and has adequate post-failure strength.

Several anchorage systems have been used to make the connections between this FRP deck and the bridge superstructure. The anchorage options are shear studs, or the Huck<sup>TM</sup> bolt fastening system combined with structural adhesives (see figure 11). The connection between the adjacent deck sections is made using Pliogrip® Series 6660 high-performance two-component polyurethane adhesive (or equivalent). There are detailed installation procedures on how to mix and apply the adhesive.

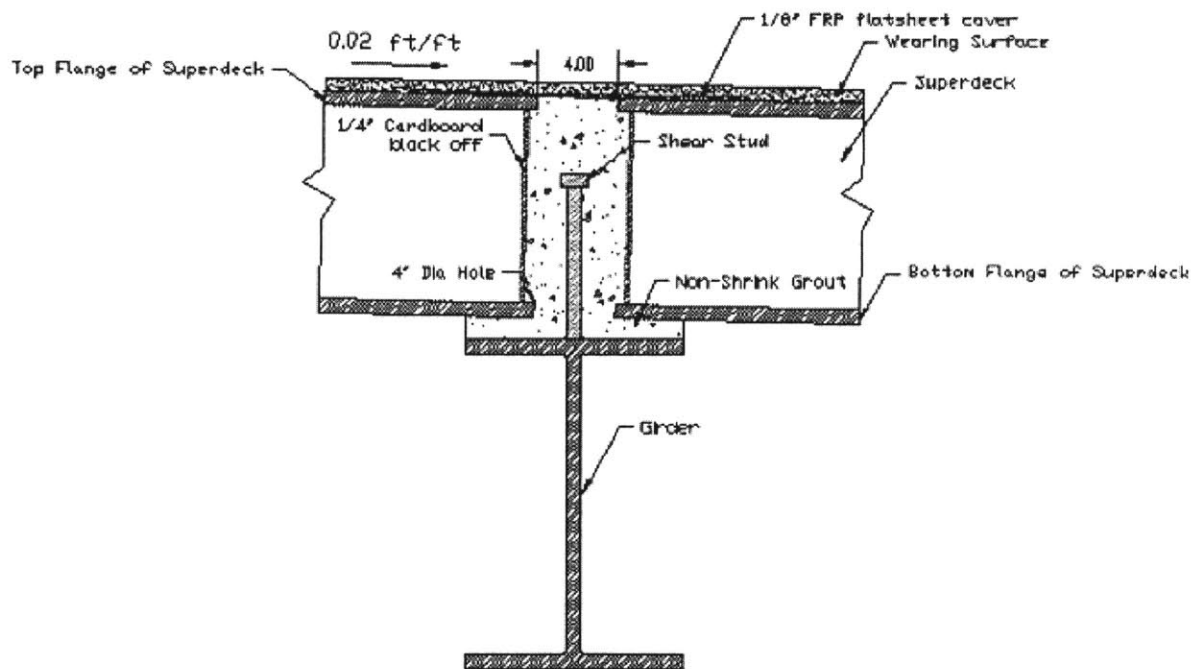


Figure 11 – Detail for Superdeck<sup>TM</sup> panel shear studs connection to steel girders.

To guarantee the superior properties of the product, a rigorous quality assurance and quality control program is undertaken that commences at the arrival of the raw materials

and continues through the installation of the product. Through each step of the process, samples are taken and tested, inspections are done and data recorded in summary reports that are kept on file for three years.

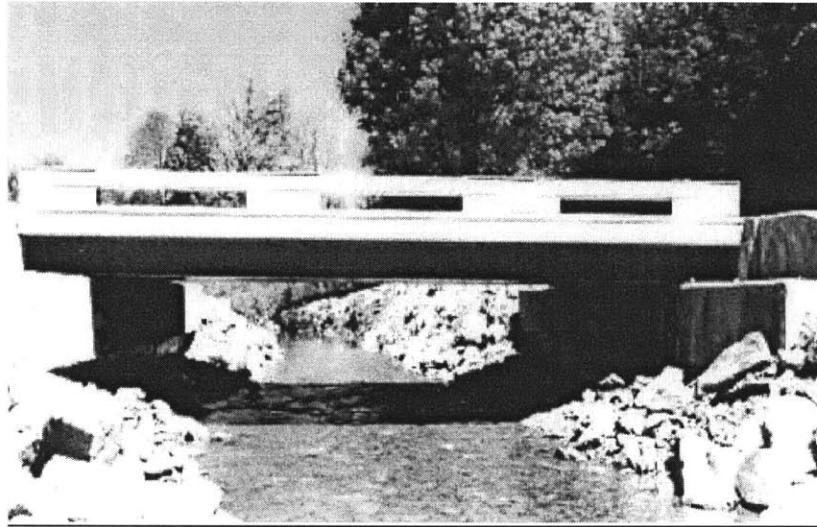


Figure 12 – Superdeck™ demonstration project in West Virginia.

### 3.2.3 Hardcore Composites

Hardcore Composites is headquartered in New Castle, Delaware and has specialized in FRP built marine infrastructure products since 1984. Since 1995, the company has also manufactured pre-engineered FRP bridge decks.

The FRP bridge deck system developed by Hardcore Composites is characterized by a lightweight, low-density, honeycomb structural core matrix surrounded by high-strength FRP face-skins. The matrix is typically made of a durable vinyl ester resin system, which is widely used for corrosion resistant marine structures, industrial chemicals processing and underground tanks. Hardcore Composites also has the capability to utilize alternative matrix materials including polyester, epoxy and phenolic if necessitated by the design. Typically, stitch bonded 72-oz/yd<sup>2</sup> quadraxial E-glass fabric with a [0/90/±45] fiber architecture is used. The face skins act to resist bending stress and provide flexural stiffness, while the core matrix acts to develop the shear transfer capacity. The deck

sections are manufactured using an adaptation of the VARTM process, which permits the fabrication of complex three-dimensional fiber architecture that can be tailored to meet the needs of the particular project. The deck can have nominal depth ranging from 8-28 in and a self-weight ranging from 20-35 psf.

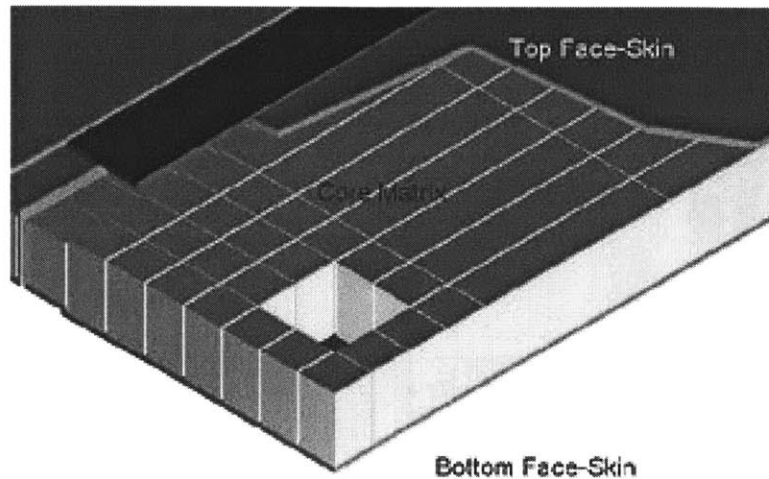


Figure 13 - Cut-away view of the cellular core honeycomb.

The FRP deck system is designed AASHTO HS25 load rating and for a deflection limit up to  $L/800$ . Accelerated testing for chemical resistance and durability was performed on coupon specimens to determine the stability of the material's tensile properties. Load tests of the bridge decks that have been installed have also been performed to confirm the predicted structural behavior.

The connections used to implement this bridge deck system are broken down into two categories. The first category is panel-to-panel connections, which are typically made using adhesively bonded butt joints or lap splices. The second category is panel to beam connections, which are typically clips, bolted fasteners or welded shear studs for steel beams and bolted fasteners, locating fasteners with shear studs or stirrups, or clip angles welded to embedded plates for concrete beams.



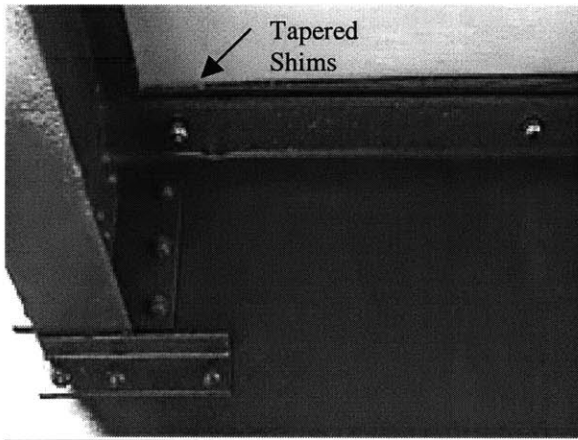


Figure 14 - FRP Deck Through-Bolted to Truss Floor Beams

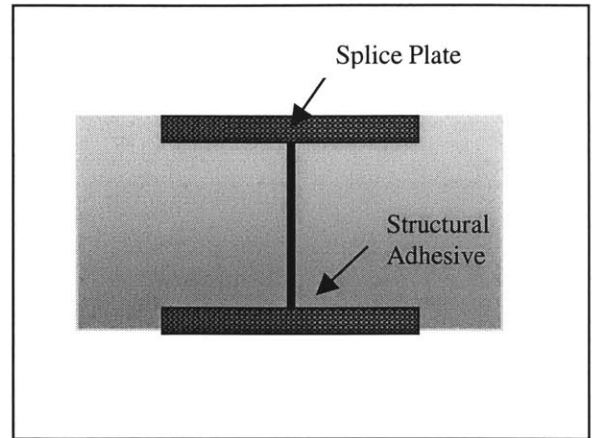


Figure 15 – Cut-Away of Splice Plate to Transfer Shear & Moment

#### 3.2.4 Kansas Structural Composites, Inc.

Kansas Structural Composites is headquartered in Russell, Kansas and was established in 1995 to introduce FRP bridge decks to the market. The company specializes in the manufacture of heavy-duty structural panels for deteriorating highway infrastructure.

The bridge deck system used is a fiber reinforced polymer honeycomb (FRPH) sandwich panel, which is manufactured using hand lay-up techniques (See figure 16). The core is approximately 0.090 in thick and consists of laminates made up of multiple layers of chopped strand mat and 40% polyester resin by weight. The face skins are composed of a non-woven mat and unidirectional combo mat. The FRP panels generally weigh 15-20% the weight of comparable products built with concrete and steel.

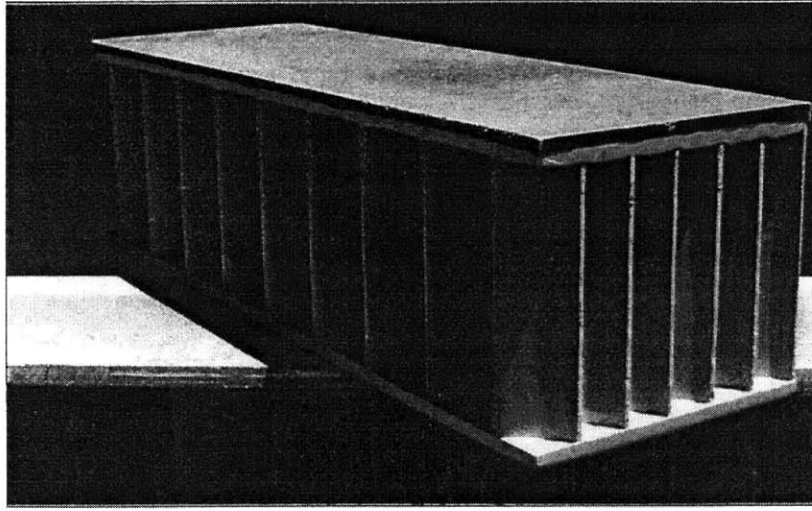


Figure 16 - Kansas Structural Composites' fiber reinforced polymer honeycomb (FRPH) sandwich panel.

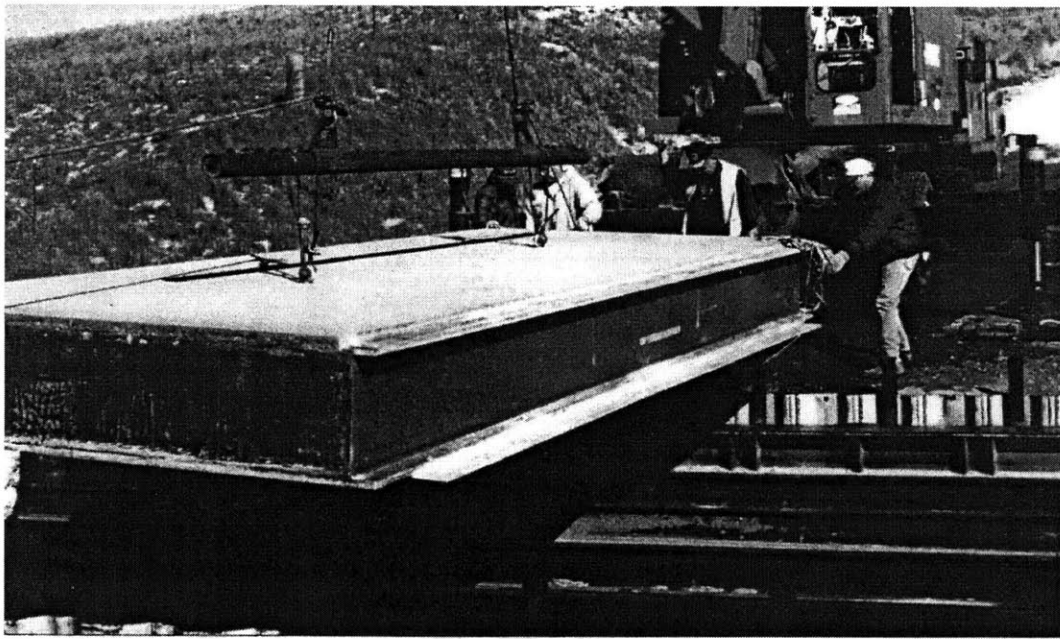


Figure 17 – Installation of Kansas Structural Composites FRP deck panel.

The FRP deck system is designed AASHTO HS25 load rating. Prior to the installation of their first FRP bridge deck, Kansas Structural Composites underwent an extensive testing program of hundreds of panels, subjecting them to flexure testing and tensile testing to ensure their structural integrity. After installation, the bridge deck has been continually monitored to ensure that the actual deflections are within acceptable limits.

Technical drawing illustrating the assembly of a repair using FRP (Fiberglass Reinforced Plastic) panels and FRPH (Fiberglass Reinforced Polymer) core, secured by a steel plate and bolts.

**Assembly Components and Dimensions:**

- FRP Panels:** 3/8" Upper Face FRP Panel and 3/8" Lower Face FRP Panel.
- FRPH Core:** FRPH Core (Fiberglass Reinforced Polymer).
- FRP Channel:** FRP Channel 5x1 3/8 x 1/2.
- FRP Tube:** FRP Tube 4x4 x 1/2.
- Steel Plate:** Steel P 15 1/2 x 14 x 3/8.
- FRP Flat Bar:** FRP Flat Bar 1/2 x 1 3/8.
- Steel P 3/4 x 4 x 11:** Steel P 3/4 x 4 x 11 w/ 2 - 1 1/8" Holes.
- Field Drill:** Field Drill 3/4" holes in FRP Tube for Installation.
- Hook Bolt:** Type AH Hook Bolt (V = 3/8") as manufactured by Linport or approved equal. 4 per assembly.
- Studs:** 1/2" Studs trapped in 3/8" Plate and welded around with 3/16" fillet weld (4 per assembly).
- Dimensions:**
  - Overall width: 1'-3 1/2"
  - Overall height: 6'-8"
  - Top section width: 4" (Typ.)
  - Top section height: 1 3/4"
  - Bottom section width: 1'-1"
  - Bottom section height: 1 1/4"
- Fill:** Fill with Polymer Concrete after installation.
- Overlay:** 3/8" Polymer Concrete Overlay.

### 3.2.4 Martin Marrieta Composites, Inc.

## Fiber Reinforced Polymer Bridge Deck Panels

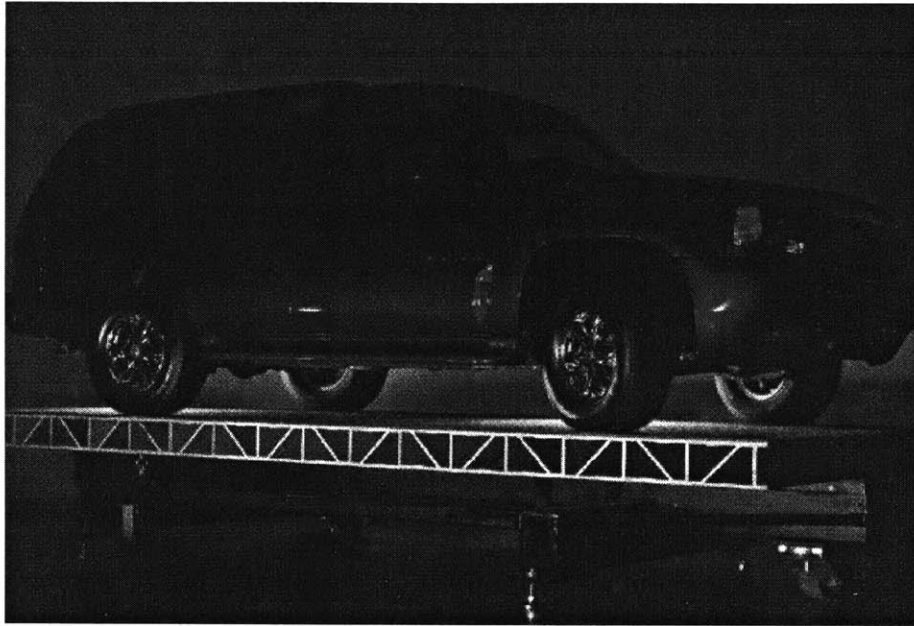


Figure 19 – Photo of exhibit demonstrating strength of MMC DuraSpan™ bridge deck.

The pre-engineered FRP deck system manufactured by MMC is the DuraSpan™ bridge deck, which was first used in 1995. The DuraSpan™ deck is characterized by its patented trapezoidal core deck tube design and a balanced quasi-isotropic fiber lay-up. (See figure 20). The composite materials used are continuous fiber reinforcements in a polymer resin binder. The reinforcements are E-glass fiberglass tows stitched into multi-ply structural fabrics. The deck panels are manufactured using the pultrusion process, in which fibers are wetted with the polymer resin and then pulled through heated metal dies, which at controlled temperatures and speeds cause the resin to cure. The pultrusion process is advantageous from the quality assurance standpoint because it allows for a complete check of the fiber content and position at frequent intervals during production.

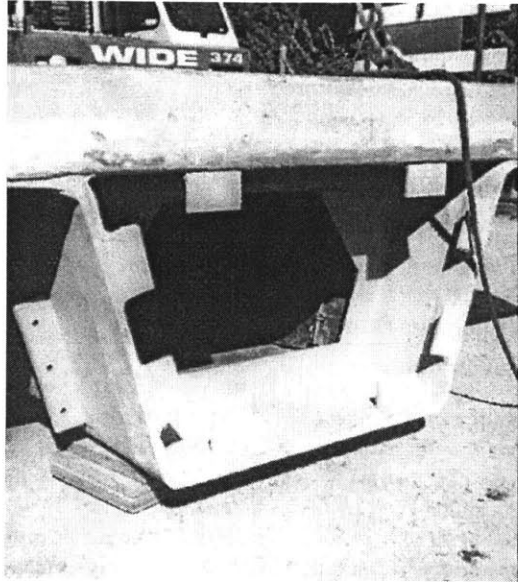


Figure 20 – Typical MMC DuraSpan™ bridge deck section.

The DuraSpan™ deck has a depth of approximately 8 in. and typically weighs 18 psf. The deck sections are typically made with a width of 8-10 ft to meet highway transport restrictions.

The FRP deck system is designed AASHTO HS25 load rating. Extensive testing has been done to confirm the predicted structural properties of the DuraSpan™ deck and connections including flexural tests, 10.5 Million load cycling tests, static transverse and longitudinal tests, durability tests and overlay tests. In addition, a long-term testing program has been implemented, which instruments and monitors the bridge decks that have already been installed.



Figure 21 – Photos from load cycling tests performed on DuraSpan™ deck.

The connections between the DuraSpan™ deck and the superstructure are made using conventional shear studs and stirrups, which create composite bending-action with the girders (See figure 22). A hole is cut into the deck, foam inserts are placed into the holes, the shear studs are field welded and then the cavity is filled with a grout. This installation process is relatively quick and simple and has a proven record of success within bridge engineering.

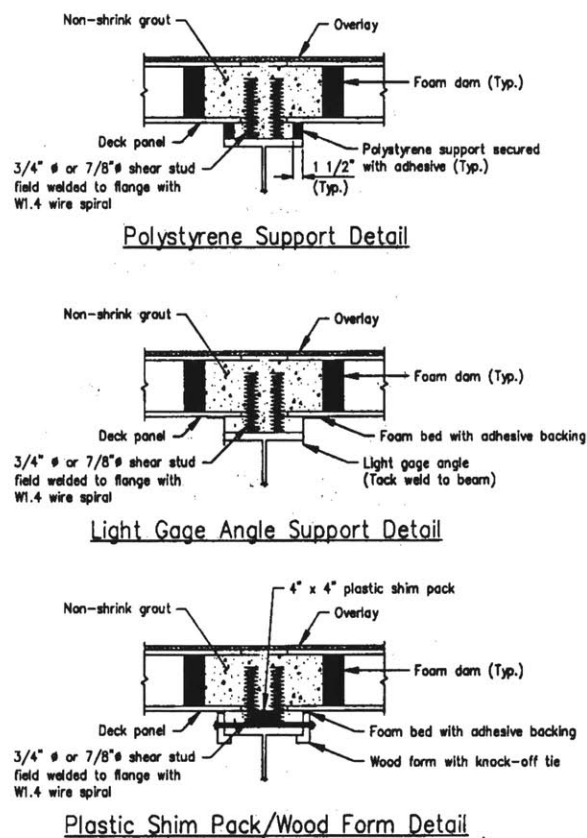


Figure 22 – Typical DuraSpan™ bridge deck connection details

### 3.3 The Manufacturers' Major Selling Points for FRP Bridge Decks

The benefits of using FRP composite materials for bridge decks is evident from the description of the technology, but the main question still remains of whether the advantages outweigh the high initial costs. The primary customers for these FRP bridge decks in the United States are the State DOTs, which are currently facing the challenge of

trying to stretch their shrinking budgets to rehabilitate their aging infrastructure. In addition to their tight budgets, State DOTs have historically been very conservative and are more apt to using proven technologies than to take a chance with an innovative solution. Manufacturers have been working closely with academia and the Federal Highway Administration studying this new technology and its viability. The main selling points of the FRP technology that the manufacturers advocate are its cost efficiency in increasing the load rating of bridges, its corrosion resistance and the speed of installation.

Many of the bridges in the U.S. are facing the possibility of being shut down or have load restrictions placed upon them because they can no longer carry the traffic loads they are subjected to as a result of structural degradation or increases in loadings. FRP deck systems offer a valuable solution to this problem because they are much lighter (~80% lighter) than their conventional material counterparts and as a result they greatly reduce the dead load on the bridge, thus allowing for an increase in live load capacity. The alternative to replacing the bridge deck with FRP would be to strengthen or replace the bridge superstructure, which can be very costly, frequently exceeding the costs of the FRP deck system. The use of FRP is especially valuable for historic bridge structures, which for preservation reasons, cannot have their superstructure altered, thus leaving no other alternative to increase the live load capacity.

One of the major causes of bridge deck deterioration is the corrosion of the steel superstructure or reinforcement, due to moisture and de-icing salts. When the conventional concrete bridge deck cracks, moisture and deicing salts seep into the deck surfaces and react chemically with the steel rebars and structural components, which then results in the formation of rust and expansion of the steel. Despite the use of additives and protective coatings, this continues to be a problem in conventional bridge decks. FRP bridge decks exhibit exceptional resistance to environmental and chemical corrosion and also serve to protect the bridge superstructure by providing an impermeable roof above it. Replacing the deteriorating bridge decks with conventional systems only provides a temporary solution to the corrosion problem, and does not address the issue of long-term sustainability of our infrastructure.

Another major issue faced by DOTs in the replacement of their bridge decks is the bridge closures that are necessary to do the construction work. Due to the modular nature of FRP bridge decks and the lightweight of the sections, the installation can be completed in a fraction of the time needed for conventional bridge decks. This is especially valuable for bridges with high average daily traffic (ADT), where long-term interruptions of service are either impossible or if they are possible, very costly. Depending on the system used and the size of the project, FRP bridge deck panels can be installed in a number of hours or days, making off- peak construction feasible. An added benefit gained by decreasing the time needed is savings in actual construction costs.

An argument that is supported by some manufacturers is the lower life-cycle cost of FRP bridge decks when compared to conventional deck systems. The life-cycle cost includes two components: direct costs and indirect costs. Direct costs include the costs of design, construction, inspection, maintenance, rehabilitation and demolition. The indirect costs include driver delay, higher vehicle operation costs and accident costs during construction, economic impacts, air pollution, noise and congestion.

These benefits that are promoted by the manufacturers offer solutions to some of the main problems that State DOTs have to face in the rehabilitation of their infrastructure assets. The majority of the bridge deck problems are the result of corrosion or insufficient load capacity, both of which can be solved cost effectively using FRP panels. In addition, FRP bridge decks offer advantages beyond their material performance in that they provide savings of time and costs in the installation, maintenance and long-term serviceability. The key now is for the State DOTs to experiment with this technology and weigh the importance of its advantages and disadvantages.



## Section 4 – Advancements and Applications of FRP in the U.S.

To investigate the true merits of FRP bridge deck panels, several state DOTs have been using the IBRC grants to fund demonstration projects. These demonstration projects have had varying degrees of success, and it is instrumental to this analysis of FRP bridge deck technology to take a look at some of the projects that have been completed in the U.S. The two projects that will be studied are the Salem Avenue Bridge in Ohio and the Bennetts Creek Bridge in New York.

### 4.1 Case Study #1 – Ohio Department of Transportation (ODOT): Replacement of the Salem Avenue Bridge Deck

One of the most significant FRP bridge deck demonstration projects completed by a U.S. DOT to date is the replacement of the deck of the 0.228 km portion of Route 49 that passes over the Great Miami River in Dayton, Ohio. This project is of particular interest because of its incorporation of FRP bridge deck panels from four different manufacturers for the purposes of research and comparison. This innovative approach to the rehabilitation of the bridge was taken by ODOT in order to both repair the deteriorating bridge and to support the FHWA's innovative materials program goals. This project was funded 80% by the FHWA IBRC program and 20% by ODOT.

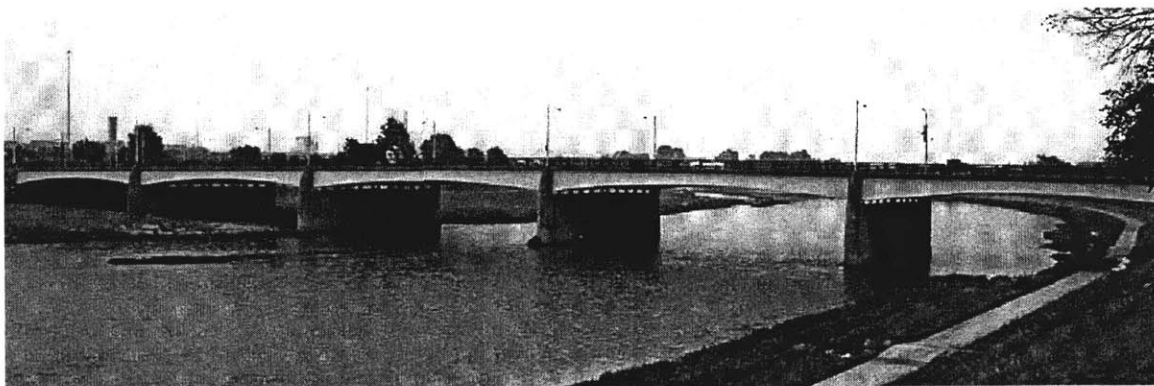


Figure 23 – Photo of the Salem Avenue Bridge prior to deck replacement.

The existing structure, built in 1951, was a 5-span, continuous, haunched plate steel girder bridge with a concrete substructure and a reinforced concrete deck, topped with a 3" bituminous surface course. The bridge carries 6 lanes of traffic over two 38-ft. wide roadways, each with a total length of approximately 680 ft. The structure was designed for a S-20-46 load rating and has a current (1999) ADT of 36,800. The proposed improvement includes the replacement of the concrete deck with a fiber reinforced polymer bridge deck, topped with a 10mm polymer concrete surface course. The bridge layout stayed basically the same, keeping the same spans and bridge dimensions. The replacement structure was designed for a MS18 loading and for a design year (2019) ADT of 47,100. The intended service life of the FRP panels is 75 years, with the wearing surface needing replacement in 15-20 years.

ODOT proposed two possible design options for the FRP deck replacement, of which design scheme #2 was implemented. (See Appendix A for project plan drawings). Design scheme #2 was a combined replacement deck program, which called for four different FRP deck systems to be used for the north roadway and a concrete deck with FRP structural form and FRP reinforcing bars to be used for the south roadway. The different FRP bridge decks were fabricated by four manufacturers including: (1) Composite Deck Solutions (CDS); (2) Creative Pultrusions, Inc. (CPI); (3) Hardcore Composites, Inc. (HCI); (4) Infrastructure Composites, Inc. (ICI). All four of the deck systems were designed for a depth of 8.5".

The deck fabricated by CDS, was utilized for the entire south roadway and for one section on the north roadway. The CDS panel is similar to a conventional concrete deck, except that glass fiber FRP bars are used instead of steel reinforcement. The deck also uses a FRP stay-in-place form to support the uncured concrete, and this form later acts as the bottom reinforcement for the deck. High performance concrete is used to provide the wearing surface.

The deck fabricated by CPI came in 8'x48' panels, which were made up of pultruded tubes, running transverse to the direction of traffic, that were shop-fabricated and

prepared. Adhesive was used to connect the adjacent panels together at the tongue-and-groove joints along the edges and to fill the non-uniform interface between the panels and the superstructure. More detailed information about the CPI deck panels can be found in the manufacturer description given in Section 3.

The deck sections fabricated by HCI, were 8'x48' sandwich panels, manufactured using a modified VARTM process. The deck section consists of a glass fiber cloth covered foam block core with fiber reinforced face skins. The adjacent panels were connected by splice plates, using a combination of screws and adhesive. Grout and adhesive were used to fill the non-uniform interface between the panels and the superstructure and to fill the pockets around the shear studs. More detailed information about the HCI deck panels can be found in the manufacturer description given in Section 3.

The deck sections fabricated by ICI, were 8'x48' sandwich panels. The panels consist of a corrugated glass fiber FRP core, with FRP face skins. Adhesive was used to connect the adjacent panels together at the tongue-and-groove joints along the edges and to fill the non-uniform interface between the panels and the superstructure.

The three FRP bridge deck systems all used a 3/8" thick polymer wearing surface manufactured and installed by Poly-Carb, Inc. The surface was first sandblasted to ensure proper adhesion, and the wearing surface was applied in two layers, with aggregate spread on top of epoxy for each layer. To simplify the installation, ODOT also designed a uniform connection detail to attach the FRP decks to the girders utilizing shear studs, spaced every 4 feet, welded to the top flange of the girders and grouted in pockets within the panels.

The ease and speed of installation is one of the major selling points for FRP bridge deck technology, so an overview of the installation of the Salem Avenue Bridge deck is valuable in determining the actual merits of FRP in this respect. Drawings of the construction sequence are included in Appendix A.

The first step in the installation of the panels (after the placement of the concrete haunch) was their placement onto the superstructure. Once the first panel was properly positioned, each of the subsequent panels was placed by a crane, about a foot from the previous panel, the necessary joint adhesives were applied, and the panel was then slid into place using a backhoe. The connection between the haunch and the panel was made by CPI using Pliogrip adhesive, by HCI using Plexus adhesive and by ICI using only pressure grouting to fill any voids. The field joints were also made differently for each deck system. The CPI deck system used adhesive to make the connection. The HCI system made the connections using splice plates that were attached using adhesives and screws. After all the panels had been placed, an adhesive was injected into the joint using a nozzle applicator. The ICI system used Pliogrip adhesive on the top and bottom plate of each adjoining panel to make the connection.

During the installation of each different deck system, there were some problems that were encountered that may have had detrimental effects on the final product. The installation of the CPI panels encountered a problem because the panels were not being placed square. By the time the sixth panel was being placed, the panels were grossly off and an adjustment had to be made to all six panels at once, shifting them back to square. This shifting may have had an adverse effect on the adhesive bond between the deck panel and the haunch. HCI also encountered problems because the panels were each slightly off dimensionally and had irregularities in all three directions. Therefore, there was difficulty in getting the adjacent panels to fit flush with each other and with getting the splice plates to seat properly. ICI encountered difficulties in the connection of adjacent panels. The male and female ends of the had to be grinded to make the proper connection, but even with grinding the proper seal could not be achieved. All these problems that were encountered could be traced back to deficiencies in the manufacturing process and lack of quality assurance and control during manufacture and installation. These problems were surprising because one of the major benefits of FRP decks are its pre-fabrication in the plant, which is supposed to result in a better quality product.

After construction had been completed and the bridge was in full operation, there were some visible signs of distress in the form of cracking and blistering. Although ODOT did not think that these deficiencies would threaten the safety or integrity of the bridge, they were concerned about the connected maintenance and serviceability issues. To address these concerns, in June 2000, they created a “third party” evaluation team, which consisted of practicing engineers. To investigate the possible deficiencies in the bridge, the team reviewed the related data, drawings, design documents, field testing reports, interviewed the deck suppliers, and performed site inspections. In addition, core samples were taken, overlay pull off and adhesion tests were conducted and analysis of the deck material properties was done. From their extensive investigation, the team was able to identify the major problems and to propose possible solutions. The findings of this investigation are broken down by deficiency below.

(1) Cracks in the concrete wearing surface

The CDS bridge deck panel exhibited a significant amount of cracking in its concrete wearing surface. Full width transverse hairline cracks were found in the negative regions of the girders and longitudinal cracks were found in random locations. The transverse cracks are expected in negative moment regions, and were within reasonable allowable limits. On the other hand, the longitudinal cracking was not expected and could be attributed to the possibility of insufficient concrete cover over the FRP reinforcement. To address this problem, the recommendation is to seal the entire deck with a high-molecular-weight methacrylate (HMWM).

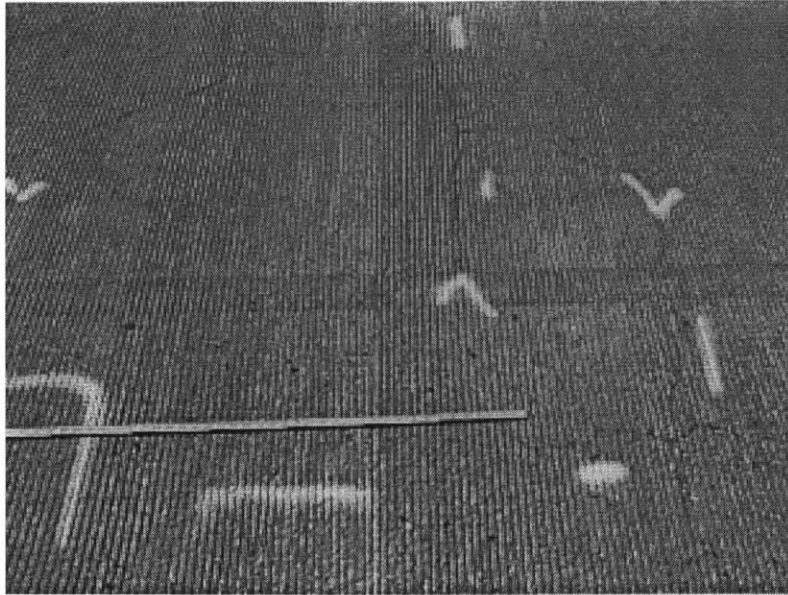


Figure 24 – Photograph of cracks in the concrete wearing surface.

## (2) Delamination and unbonded areas in panel skins

From the results of visual inspections and non-destructive testing, it was found that the panel skins of the HCI and ICI deck panels had sections that were delaminated and/or unbonded. The reason for this delamination is suspected to be either improper installation practices or to defects in the manufacturing process and quality assurance. To immediately address this problem, all the deck delamination must be repaired. In the long-term, both of the deck manufacturers must test the panels to determine what the actual cause of the deficiency is and how much delamination can be sustained before there is loss of stiffness or stress. The manufacturers must identify any flaws in the design and manufacturing process and address them to ensure their deck systems are structurally sound.

## (3) Deck-to-girder connection at the haunches

From the instrumentation data, it was found that the CPI, HCI and ICI panels were not satisfactorily connected to the haunch because under cyclic loads, some of the panels moved as much as 1/16" vertically and rotated. The movement can be attributed to a

number of possible causes including loose or broken stud anchors, failure of the grout in the stud pockets or at panel/haunch interface and reactions from thermal expansion/contraction. The possibility of long-term fatigue problems as a result of this movement should be investigated. To eliminate this problem, ODOT must ensure that there is uniform bearing on the haunches and that the connections between the deck and the haunch are satisfactorily made.

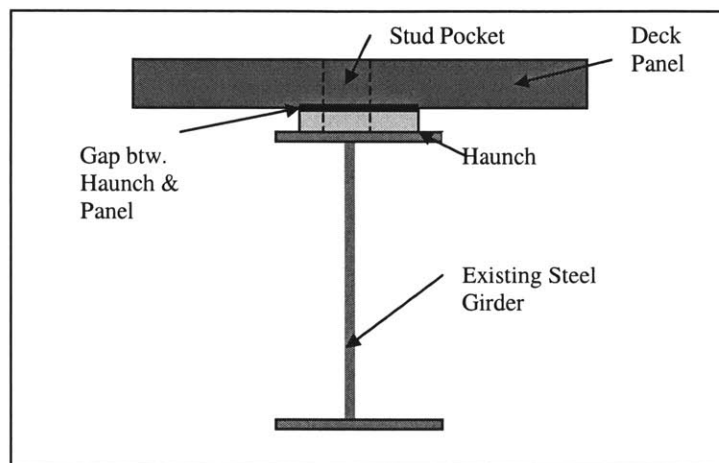


Figure 25 – Deck-to-girder connection.

#### (4) Field and shop joint problems

Upon visual inspection, it was found that the polymer wearing surface had cracked above the field joints for all three types of FRP decks. It is suspected that this was due to the unevenly applied adhesive and incomplete bonding of the vertical surfaces of some of the adjacent deck panels. The HCI panels were exhibiting additional problems at their panel-to-panel splice plate connections, which were deflecting under the loads, due to insufficient or poor bonding. In addition, the inadequacy of the HCI and ICI panels' joints was evident from the substantial water leakage through these panels and onto the bridge superstructure during rainstorms. In order to address this problem, the team recommends that the joints be stripped of their wearing surface, cleaned, repaired and reinstalled properly.

#### (5) Deficiencies in polymer wearing surface

The polymer wearing surface was found to have cracks at the field joints between all the deck panels, with some related debonding from the deck panels, as well as cracking at the shear stud cover plates. The cracking in the wearing surface is due to inadequate strain capacity, inadequate adhesion between deck and wearing surface, poor fit-up and incomplete shear transfer in the FRP panels. This cracking should be eliminated once the issues with the panel face sheets and the field joints have been resolved. Once these problems are repaired, the wearing surface should be removed and reapplied.



Figure 26 - Cracks in polymer wearing surface at a deck joint.

#### (6) Joints between different deck systems

The major problem with these joints was found to be the differential deflection of the adjacent deck panels. These differential deflections ranged from 1/64" to 1/8". Under heavy loads, one panel would deflect more than the next and a large impact force would then act on the second panel. The deck panels could be subject to damage due to these differential displacements and the differences in the stiffness of the decks. To eliminate



this problem, the recommendation is to develop diaphragms to provide end support and connectivity at these joints.

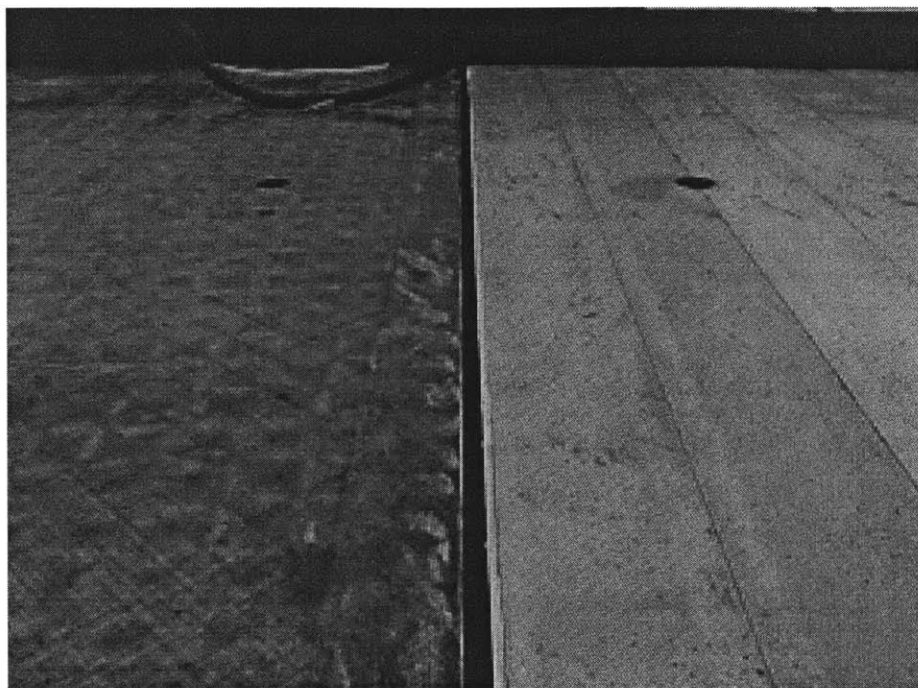


Figure 27 – Joint between the HCI and CPI deck panels.

#### (7) Water intrusion

Water was found inside of the HCI, CPI and ICI deck panels. Possible entry points for the water include the stud anchor holes, holes drilled for attachments, or condensation. Water inside the panels could endanger the structural integrity of the system and could also lead to freeze-thaw effects. The recommended solution would be to drill drain holes for the release of the entrapped water.

#### (8) Flaws in deck cross section

From a visual inspection of the four deck sections, flaws were found in the ICI and HCI panels. The ICI panels had detectable small and scattered voids, which is typical of hand laid laminates. A major deficiency that was found was that the face sheets were not

bonded to the core webs. The HCI panels had frequent, relatively large voids existing within the ply interface beneath the webs and the bottom face sheet. The deficiencies found in both these problems are due to poor fabrication techniques and quality control and must be addressed by the manufacturers.

By performing this thorough investigation of the bridge project, valuable information was collected on the performance of the different types of deck systems, when they are subjected to similar conditions. The problems found with these deck sections can be traced back to issues with the design, the fabrication, the installation or the quality assurance and steps could be taken to formulate repair methodologies and more importantly, refine the designs and incorporate preventative measures for future applications. From this experience, ODOT has learned that there is a need for open communication and cooperation between all involved parties, for more detailed and accurate design and construction documentation, for increased field support and inspection by the deck supplier, for the development of specifications, for increased quality assurance and control, for improvements in installation sequencing, for the manufacturers to provide written installation guidelines and for the manufacturers to provide and be responsible for satisfactory panel connections. These lessons learned can be incorporated into their procurement process for the next FRP bridge project and so on, with the cycle continuing and leading to the advancement and spread of this technology. Besides being valuable to ODOT, this information can be shared with other DOT's across the U.S. so that they may learn from ODOT's mistakes and make further progress with their own FRP projects.

#### 4.2 Case Study #2 – New York State Department of Transportation : Rehabilitation of the Route 248 bridge over Bennetts Creek

A bridge deck replacement that is more typical in size and scope to the majority of the FRP deck projects that have been completed in the U.S. thus far is the Route 248 bridge project over Bennetts Creek in Steuben County, New York. The percentage of deficient bridges in NYS is higher than the national average, due to the corrosive effects of deicing

salts. To combat this problem, NYS has been actively involved in experimenting with innovative methods of rehabilitating the structures and prolonging their service lives. In the Bennett Creek project, the bridge structure had been significantly deteriorated due to deicing salts, with full depth holes on the curb and a slab that has been overlaid so many times that its depth had reached over 34". The existing structure was built in 1926, consisting of a reinforced concrete slab system carrying a total of 4 lanes, measuring 33 ft wide, across a 25 ft span. Due to its deteriorated condition, the bridge was posted with a 10-ton weight restriction in 1997, which forced the heavier traffic to use local roads, resulting in an increased cost to the drivers and damage to these county roads.



Figure 28 – Deteriorated superstructure of the Bennetts Creek Bridge.

In 1998, the county made the decision that the bridge had to be replaced and thought that the structure provided an excellent opportunity to further their investigation efforts into the feasibility of using FRP bridge decks. The existing bridge was demolished in April of 1998 and a temporary detour bridge was built. The FRP superstructure was designed and manufactured by Hardcore Composites. The specifications required the bridge to be designed for a HS25 loading, a deflection limit of  $L/800$  and for future growth of the

ADT from its 1998 value of 300. The FRP bridge deck was manufactured using the resin infusion molding process, and was fabricated from an e-glass-stitched bonded fabric and vinyl ester resin. The deck structure utilized a cell-core system, with top and bottom fiber mats, and had a final depth of 24.5", topped with a 0.4" thick polymer-concrete wearing surface. For more details about Hardcore Composite's deck system see Section 3. The bridge's approach slabs are made from reinforced concrete and the connection is made with the FRP deck using a pourable silicone seal. See Appendix B for the plan, elevation and cross section drawings for this project.



Figure 29 – Photo of Bennetts Creek Bridge replacement road surface.

The deck was manufactured in 2 sections, to meet the shipping constraints. Due to the lightweight of the sections, they were transported from the manufacture to the site using a truck, at a total cost of \$7,000. Once on the site, a NYS Bridge maintenance crew performed the installation of the panels. In preparation for the superstructure installation, neoprene bearing pads were placed on the abutment bridge seats, and holes were drilled for the anchor dowels at the centerline of bearings. The panels were lifted and placed at a 0.4 in spacing using a 75 ton capacity crane.



Figure 30 – Placement of the first half of the superstructure.

The panels were anchored using 1" stainless steel Hilti anchors that were drilled and grouted into the concrete bridge seat. To join the panels, acrylic adhesive was placed on the bottom backer plate and the gap between the two panels was filled with an adhesive. Finally, the anchor bolt openings on the deck were filled with a non-shrink grout and the centerline joint was filled with a silicone sealant. The entire erection of the superstructure as described here was completed in approximately six hours. After the erection of the superstructure was complete, there still remained several weeks of construction work to be completed. The remaining work included the placement of the concrete approach slabs, wingwalls and traffic barriers, the installation of the silicone joint between the deck and the approach slabs, the asphalt paving and the installation of the steel box beam bridge and approach railing. The bridge work was completed and opened for service in less than two months after the delivery of the panels.

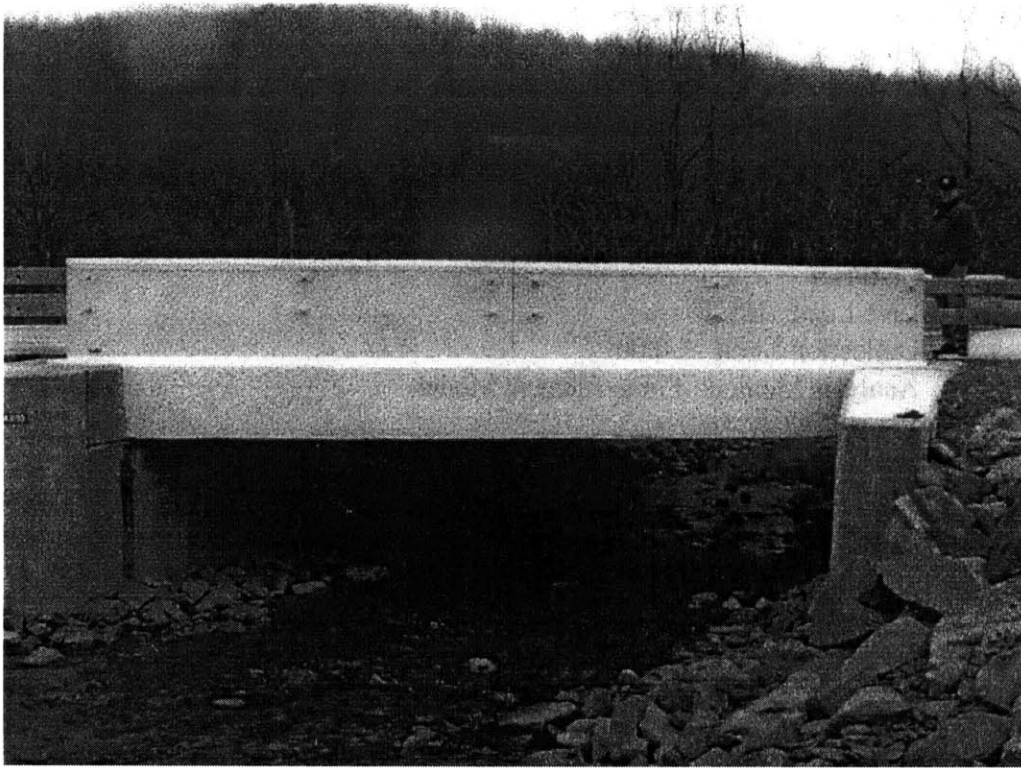


Figure 31 – Completed Bennetts Creek FRP bridge deck.

Prior to opening the bridge up for traffic, a load testing program was undertaken to ensure the structure's integrity, to study the actual performance of the structure (vs. the calculated values) and to establish a benchmark to use in future monitoring of the structure. The structure was instrumented using 24 strain gauges to investigate the strain along the structure, the load distribution, the deflection, and to collect data for the proof load test. The results of these test were all within the acceptable limits given within the DOT's specifications.



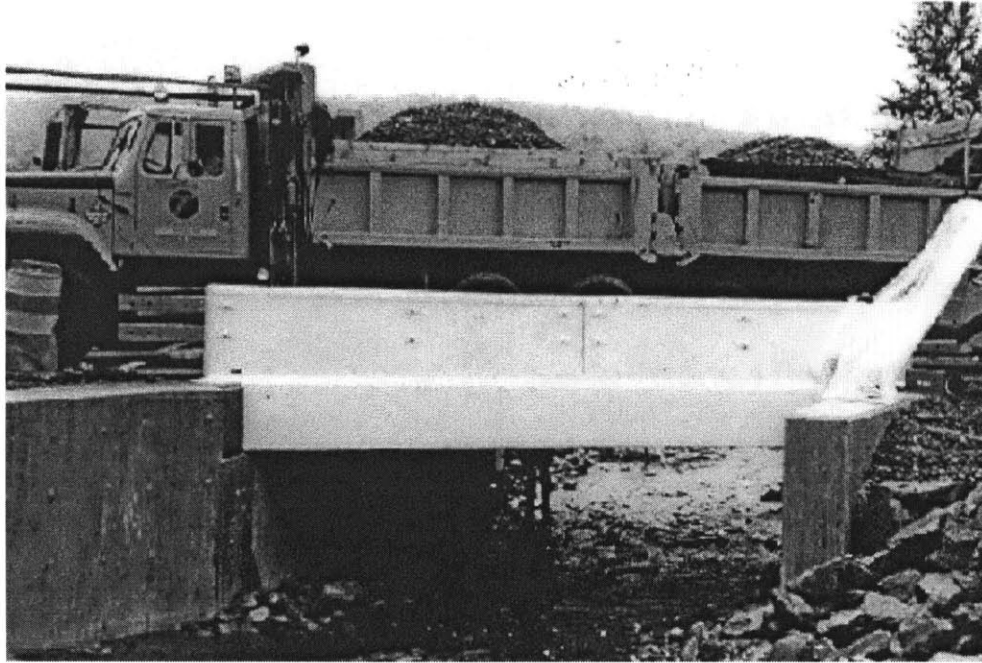


Figure 32 – Load testing of the FRP superstructure.

A long-term load testing program has been set up to monitor the bridge deck performance at 6-month intervals. Thus far, the follow-up tests have shown results consistent with the data collected in the initial testing. Due to the experimental nature of this structure, frequent visual and tactile inspections have been performed of the superstructure and the wearing surface. Thus far, the only problem that was found was that there was excessive wear of the polymer-concrete surface after 1.5 years. The wearing surface had to be removed and replaced in June 2000.

The NYSDOT was very pleased with the ease and speed of the FRP bridge deck installation. Because of the modular nature of the system, they were able to install it in less than a day, and were able to utilize their own maintenance crews to perform the work. In addition to being extremely cost effective, it also delivered a finished product in a much shorter time period than would be expected for a conventional bridge deck. The time from the demolition of the bridge to the opening of the bridge was about 6 months, which is a quarter of the time NYSDOT had estimated would be needed to complete the project had a conventional system been used.

In interviews with several of the bridge engineers at the NYS DOT, they communicated their views of the benefits and shortfalls of this new technology. As was seen in the Bennett's Creek Bridge, there have been problems with getting the polymer concrete overlay to bond properly, which may lead to water penetration, freeze-thaw damage and spalling. They suspect that this problem can be attributed to inadequate surface preparation. In addition, the polymer overlays have been exhibiting significant wearing due to the snow removal efforts during the past few rigorous winters. The engineers feel that to solve this problem, the manufacturer should always have a qualified representative on site during installation and should help write an installation specification so that contractors (as opposed to maintenance crews) can be hired for the work.

Since this project has been completed, the NYS DOT has continued to use their growing knowledge of this innovative material to construct 4 additional FRP bridge decks.

#### 4.3 The DOTs' standpoint on the viability of this new technology

The majority of FRP bridge decks in the U.S. have been installed by the State DOTs, using grants from the IBRC program. Since they are the biggest customers for these innovative bridge decks, interviews were conducted with 7 of the DOTs involved to determine their experiences thus far and their predictions of the viability of this material in the future.

The majority of the DOTs interviewed were satisfied, on the whole, in their experiences with FRP bridge decks. The major benefits of the FRP deck that were repeatedly mentioned were its lightweight and the speed of installation. Because of its lightweight, the main application that the DOTs saw for the FRP decks was in increasing the load rating of an existing bridge. Since many bridges no longer have the capacity to take the loadings they are subjected to, they must either be strengthened or load posted. The FRP deck offers an optimal solution because it substantially reduces the dead load on the structure, freeing up the live load capacity that is required without any changes having to be made to the superstructure. This is especially valuable for historic bridges, which due



to preservation requirements can not be altered in physical appearance, ruling out most strengthening techniques. The speed of installation was also very valuable to the DOTs because the delays and inconveniences the rehabilitation or construction of bridge decks result in are very costly and opposed to by the general public. The fact that the installation can be completed in a fraction of the time usually required can be a major factor in the utilization of this technology, especially in areas with high levels of traffic. Another possible market, suggested by the NYS DOT that could result from the fast installation time is in emergency bridge replacement panels. If the manufacturers could have a catalogue of standard sections that were readily available, this combined with the ability to quickly install the sections would be invaluable in an emergency situation.

The DOTs that showed support for the FRP decks, did experience some problems on their projects and had many suggestions for improvements that had to be implemented in order for this technology to grow and become accepted in the future. The major issue was the current cost of the FRP deck, which is 3-4 times that of a comparable conventional concrete deck. Although the DOTs are aware that the FRP deck's life-cycle costs may be lower than a conventional deck's, it is hard for them to justify investing the same amount of money to complete a third or fourth of the projects, especially in the current poor state of the nation's infrastructure. It is especially difficult to justify for the construction of a new bridge because the high initial costs do not offer the bridge a substantial amount of advantages in the short run.

Another major issue that must be addressed is the quality of the connections and field joints. Due to the unsatisfactory design, manufacture and/or installation of the connections and joints, there have been problems with differential movements, delamination, substantial displacements/rotations and with water penetration.

The polymer concrete wearing surface that has been used for the majority of the FRP decks installed has also been causing problems for many of the DOTs. There have been several cases of poor adhesion, cracking and water penetration. Some DOTs have said that with proper surface preparation, they have been able to eliminate these problems, but

other DOTs have stopped using this wearing surface altogether and are using asphalt instead.

In addition, due to the cutting-edge nature of the FRP technology, the DOTs are looking for the creation of specifications for design, installation and construction, the writing of a code and the collection of long term data. Of course, this data and supporting documentation cannot be created overnight, but rather must be compiled as more research and experimentation are done.

Maine's DOT offered an interesting contrast to the other DOTs experiences and opinions of this innovative technology. Maine's DOT did much research into innovative materials and expressed disappointment in their findings about the performance of FRP. The DOT felt that FRP was too expensive, with insufficient advantages to justify the high costs. Some of the specific concerns they had about the FRP deck performance were the high uncertainty in the designs and the delamination problems experienced with the overlay. They did not think the ability of FRP to increase load ratings was much greater than composite steel/concrete systems, which are much more cost efficient. In addition, they did not have great need for the quick installation time since none of their bridges have ADTs over 8000. Overall, they felt that their concrete bridges were performing satisfactorily and that investment in FRP research and projects was not a priority.

On the whole, the State DOTs seem to be supportive of this new technology and willing to continue to work along with the manufacturers to improve it. Thus far the viability of this product in the DOTs eyes seems to be in increasing bridge load ratings and in high ADT areas.

#### 4.4 Steps the Manufacturers are taking to address the needs of the DOTs

In order to assure the growth and expansion of the FRP bridge deck market, the manufacturers must acknowledge the DOTs' concerns and recommendations and work on improving this technology. They must collaborate with the State DOTs, the bridge

engineering community, the code agencies, the contractors and research institutions in order to gather data and share the information that is necessary to make this material competitive in the future. Interviews were conducted with several of the major manufacturers to get an understanding of how they are advancing their products and making them more competitive.

The most important issue that the manufacturers want to address is the high initial cost of the FRP decks. The advantages of FRP decks in certain special applications may be sufficient to justify their use over conventional materials, but in order for FRP to attain widespread use, it must become cost competitive. This is a difficult challenge for the manufacturers because such a high percentage of the cost is due to the high material costs and as a result, the only way to significantly decrease the costs is to streamline the design. Design methods must be optimized and additional research must be done in order to eliminate over-conservative designs and minimize the quantity of resin and fiber used in structures. In addition, steps can be taken to make the manufacturing process more efficient so that decks can be fabricated faster and at a lower cost. Kansas Structural Composites believe that by taking these steps, they will be able to produce a product that is cost competitive with concrete within three years.

To address the problems that have been encountered due to poor installation of the bridge deck section by the contractors, the manufacturers are working to develop installation guidelines and to ensure adequate supervision during installation. Many of the performance problems that the DOTs have encountered in their FRP deck projects have been traced back to installation errors. Since the contractors that are performing this work do have much prior experience with FRP decks, they need detailed guidelines in order to satisfactorily complete the work. In addition, since the manufacturers are the most familiar with this technology, they are the best equipped to offer guidance during the installation. The manufacturers are aware of this and have pledged to form a close working relationship with the contractors in hopes of producing a high quality final product.

The other design issues that the manufacturers must address are the connections and field joints. Further research is being done in collaboration with research institutions to formulate adhesives and fasteners that are customized to work with the material properties of their particular FRP deck systems.

Another interesting project that is being worked on by Kansas Structural Composites is the creation of standardized deck panels that can be used for emergency deck replacements. Their goal is to create a section that can be ordered and installed overnight so that traffic can resume using the bridge in the morning. If this project is realized, this will open up a sizeable market for FRP decks because DOTs will be willing to pay for the installation efficiency that can be provided by the decks.

The steps that the manufacturers are currently taking to address the needs of their market are in the right direction and will help them establish themselves within the infrastructure market. It will be a great challenge for them to overcome the DOTs conservative attitude towards innovation, but with a continued commitment to research, refinement and cooperation, the success of FRP deck is foreseeable

## **Section 5 - Future of the FRP Deck Industry**

The future of FRP bridge deck technology lies in the hands of all the parties that are involved and is dependent on their cooperation and dedication to its advancement. In the few years since their introduction to the infrastructure industry, FRP bridge decks have made large strides in application and development with the relatively successful IBRC funded demonstration projects. As was revealed in the research done for this paper, FRP bridge deck technology still has a long way to go before it can anchor itself as a mainstay in the U.S. infrastructure industry. To continue the advancement and expansion of this technology, the issues that have been identified must be addressed and acted upon.

The issue that has repeatedly been heralded as the main determining factor of the success of FRP decks is the cost of the technology. Currently, a FRP deck costs 3 to 4 times as much as a comparable concrete deck. For this cost, the DOTs can very often replace the entire bridge structure. As a result, it is difficult to justify this investment unless the FRP bridge deck provides benefits that are worth the additional costs. The DOTs have identified several applications that they feel meet this criterion. Their satisfaction with the performance of FRP decks in rehabilitation of structures that need increased load rating and for structures in high ADT areas is evident from the study done. Due to FRP's unique performance capabilities in these areas, the growth and sustainability of FRP bridge decks in this arena is promising in the near future. On the other hand, in order for FRP to compete with the conventional materials in new construction, measures must be taken to drive the cost down. The nature of the DOT procurement process is to select the lowest qualified bidder and without a competitive cost, FRP cannot have a future in this market. Although the lower life-cycle costs of FRP have been advocated, the DOTs are not mandated to account for this and do not have sufficient funding in their budgets to justify higher initial costs for future savings. Therefore, costs must be driven down by streamlining the design and manufacturing process, increasing the automation, standardizing the sections and reducing the weight.


The other main issue that presents an obstacle to the advancement of FRP bridge decks is the lack of construction specifications, installation specifications and a design code. The construction industry, especially in the public sector, is very cautious in accepting changes or innovations in technology because of the liability and costs associated with the uncertainty. Therefore, it is difficult for the DOTs to utilize a technology that they are unfamiliar with especially when they do not have any governing document that can guide them through the design, installation and construction process. Most bridge engineers do not have any experience with FRP composites and can only try to apply their knowledge of conventional isotropic materials to understand the behavior of this complex material. This issue is universal to all new technologies because of the lack of research and long term data. The only way for the FRP bridge deck industry to overcome this issue is to work along with research institutions to investigate and test FRP material properties and performance so that the data can be collected and developed into specifications and codes. Several groups are currently working to create a design code including the National Institute of Standards and Technology (NIST), the American Association of State Highway Officials (AASHTO) and the European Structural Polymeric Composites Group. They are using the existing material and bridge codes as guidelines to shape their research and analysis.

The public and private sectors must share their ideas and resources, as well as development costs, personal assets, proprietary ideas, and the risks associated with FRP bridge decks in order to satisfactorily address the issues that have been identified. If viable methods of overcoming these hindrances can be found, FRP bridge decks may be able to become a mainstream material. But, as is the case with all new materials, it will take many years of experience and research for it to gain wide-spread acceptance. The reaction that FRP has received by the construction industry can be compared to the reaction to steel in the 1800's, which was equally as cautious. It took 30-40 years for steel to become widely accepted and to be considered cost effective for civil engineering applications.

The point that must be stressed is that the successful implementation of FRP bridge decks and other innovative solutions to the U.S.'s infrastructure problems can be rewarding to all the parties that are involved. The reward to the public sector will be the recognition it will get for re-establishing the U.S.'s infrastructure network and technology as the leader in the world. For the private sector, the rewards will be the patents, rights-to-manufacture and the profits. The future of FRP bridge decks in the infrastructure applications is very promising and will succeed if the public and private sector are willing to expand their horizons and push the envelope beyond what has been conventionally used, continually advancing and learning from these new experiences.

# Appendix A






**LOCATION MAP**  
 LATITUDE: 39°45'42" LONGITUDE: 84°12'12"  
 SCALE IN KILOMETERS  
 PORTION TO BE IMPROVED: \_\_\_\_\_  
 STATE & FEDERAL ROUTES: \_\_\_\_\_  
 OTHER ROADS: \_\_\_\_\_

STATE OF OHIO  
 DEPARTMENT OF TRANSPORTATION

# MOT-49-1.634

CITY of DAYTON  
 MONTGOMERY COUNTY



**DESIGN DESIGNATION**

CURRENT ADT (1999)	36800
DESIGN YEAR ADT (2019)	47100
DESIGN HOURLY VOLUME (2019)	1962
DIRECTIONAL DISTRIBUTION	.55
TRUCKS (24 HOUR B&C)	700
DESIGN SPEED	55 km/hr
LEGAL SPEED	35 mph

DESIGN FUNCTIONAL CLASSIFICATION -  
 MINOR ARTERIAL-URBAN

**DESIGN EXCEPTIONS**  
 None Required

**INDEX OF SHEETS:**

Title Sheet	1
Schematic Plan	2
Typical Sections	3
General Notes	4
Maintenance of Traffic and Detour	5-11
Maintenance of Traffic Sub-Summary	12
General Summary	13
General Plan - Alternates 1 & 2	14-15
Plan & Elevation	16-17
Estimated Quantities & Structure Notes	18, 18A, 18B, 18C, 19
Structure Details	20-32
Utility Details	32-34
Traffic Control	35

**PROJECT DESCRIPTION**

Improvement of 0.228 km portion of State Route 49 in City of Dayton, Montgomery County by replacing the deck of a structure over the Great Miami River with a Fiber Reinforced Polymer Composite deck structure including approach reconstruction.

**1997 SPECIFICATIONS**

The standard specifications of THE STATE OF OHIO, DEPARTMENT OF TRANSPORTATION, including changes and supplemental specifications listed in the proposal shall govern this improvement.

I hereby approve these plans and declare that the making of this improvement will require the closing to traffic of the highway and that detours will be provided as indicated on sheets no. 5 thru 11 of 35.

**UNDERGROUND UTILITIES**  
 TWO WORKING DAYS  
**BEFORE YOU DIG**  
 Call... 800-362-2764 (toll free)  
 OHIO UTILITIES PROTECTION SERVICE  
 NON-MEMBERS  
 MUST BE CALLED DIRECTLY

PLANS PREPARED BY:  
 Ohio Dept. of Transportation  
 District Seven &  
 Office Structural Engineering

STANDARD CONSTRUCTION DRAWINGS				SUPPLEMENTAL SPECIFICATIONS
AS-1-81N 10-25-94	BR-2-26N	EX-1-87N 3-20-95	MT-95-31N 4-25-94	MT-95-32N 4-25-94
MT-95-31N 4-25-94	MT-95-32N 4-25-94	MT-95-33N 6-24-93	MT-95-34N 6-24-93	MT-95-35N 6-24-93
MT-95-36N 4-25-94	MT-95-37N 4-25-94	MT-95-38N 4-25-94	MT-95-39N 4-25-94	MT-95-40N 4-25-94
MT-95-41N 4-25-94	MT-95-42N 4-25-94	MT-95-43N 4-25-94	MT-95-44N 4-25-94	MT-95-45N 4-25-94
MT-95-46N 4-25-94	MT-95-47N 4-25-94	MT-95-48N 4-25-94	MT-95-49N 4-25-94	MT-95-50N 4-25-94
MT-95-51N 4-25-94	MT-95-52N 4-25-94	MT-95-53N 4-25-94	MT-95-54N 4-25-94	MT-95-55N 4-25-94
MT-95-56N 4-25-94	MT-95-57N 4-25-94	MT-95-58N 4-25-94	MT-95-59N 4-25-94	MT-95-60N 4-25-94
MT-95-61N 4-25-94	MT-95-62N 4-25-94	MT-95-63N 4-25-94	MT-95-64N 4-25-94	MT-95-65N 4-25-94
MT-95-66N 4-25-94	MT-95-67N 4-25-94	MT-95-68N 4-25-94	MT-95-69N 4-25-94	MT-95-70N 4-25-94
MT-95-71N 4-25-94	MT-95-72N 4-25-94	MT-95-73N 4-25-94	MT-95-74N 4-25-94	MT-95-75N 4-25-94
MT-95-76N 4-25-94	MT-95-77N 4-25-94	MT-95-78N 4-25-94	MT-95-79N 4-25-94	MT-95-80N 4-25-94
MT-95-81N 4-25-94	MT-95-82N 4-25-94	MT-95-83N 4-25-94	MT-95-84N 4-25-94	MT-95-85N 4-25-94
MT-95-86N 4-25-94	MT-95-87N 4-25-94	MT-95-88N 4-25-94	MT-95-89N 4-25-94	MT-95-90N 4-25-94
MT-95-91N 4-25-94	MT-95-92N 4-25-94	MT-95-93N 4-25-94	MT-95-94N 4-25-94	MT-95-95N 4-25-94
MT-95-96N 4-25-94	MT-95-97N 4-25-94	MT-95-98N 4-25-94	MT-95-99N 4-25-94	MT-95-100N 4-25-94

**APPROVED**  
 DATE \_\_\_\_\_ DISTRICT DEPUTY DIRECTOR

**APPROVED**  
 DATE \_\_\_\_\_ DIRECTOR, DEPARTMENT OF TRANSPORTATION

**DESIGNER'S SEAL**

**BRIDGE ENGINEER'S SEAL**

**UNDERGROUND UTILITIES**

**BEFORE YOU DIG**

**OHIO UTILITIES PROTECTION SERVICE**

**NON-MEMBERS**

**MUST BE CALLED DIRECTLY**

**PLANS PREPARED BY:**

Ohio Dept. of Transportation  
 District Seven &  
 Office Structural Engineering

**APPROVED**  
 DATE \_\_\_\_\_ DISTRICT DEPUTY DIRECTOR

**APPROVED**  
 DATE \_\_\_\_\_ DIRECTOR, DEPARTMENT OF TRANSPORTATION

**DESIGNER'S SEAL**

**BRIDGE ENGINEER'S SEAL**

**UNDERGROUND UTILITIES**

**BEFORE YOU DIG**

**OHIO UTILITIES PROTECTION SERVICE**

**NON-MEMBERS**

**MUST BE CALLED DIRECTLY**

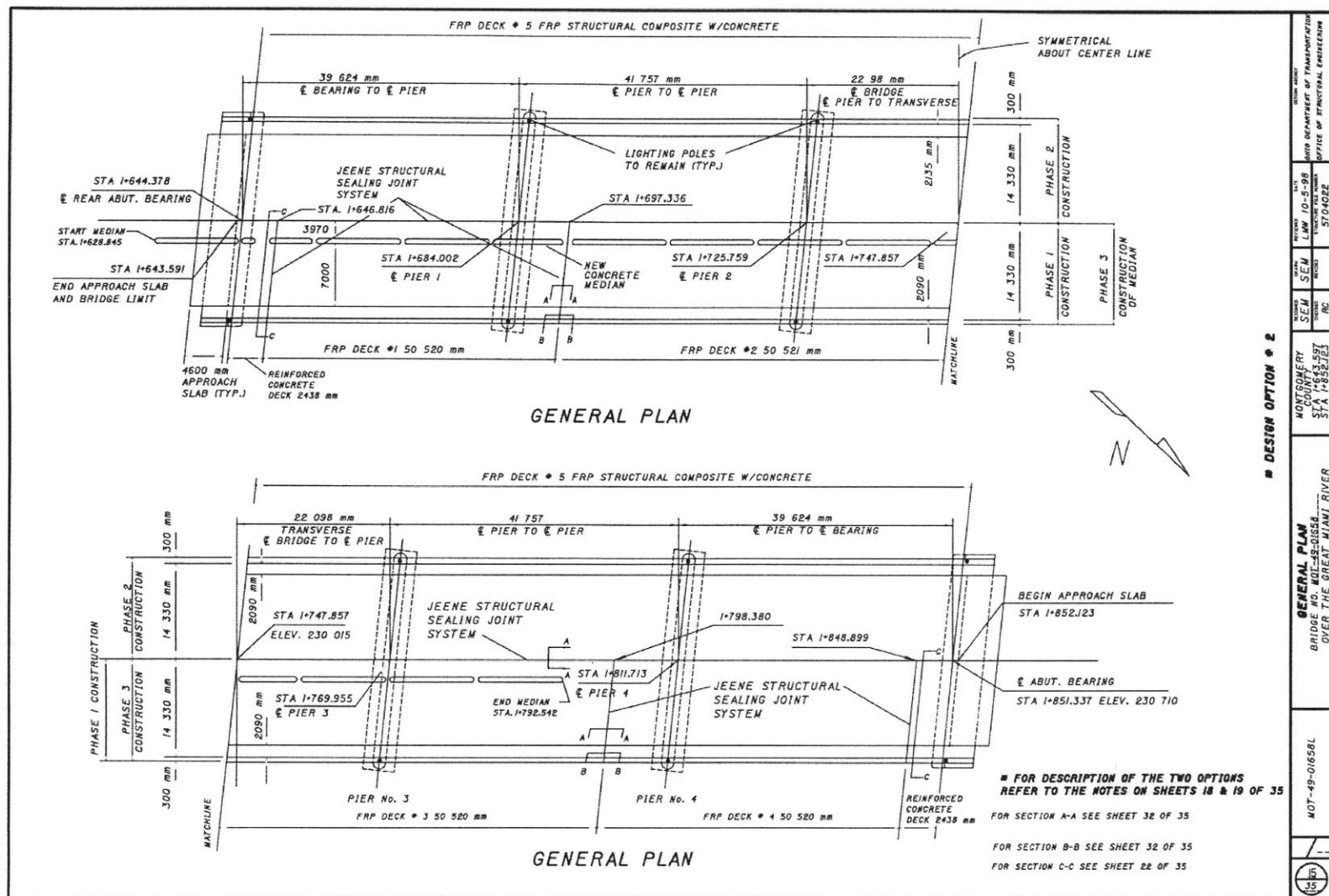
**PLANS PREPARED BY:**

Ohio Dept. of Transportation  
 District Seven &  
 Office Structural Engineering

**APPROVED**  
 DATE \_\_\_\_\_ DISTRICT DEPUTY DIRECTOR

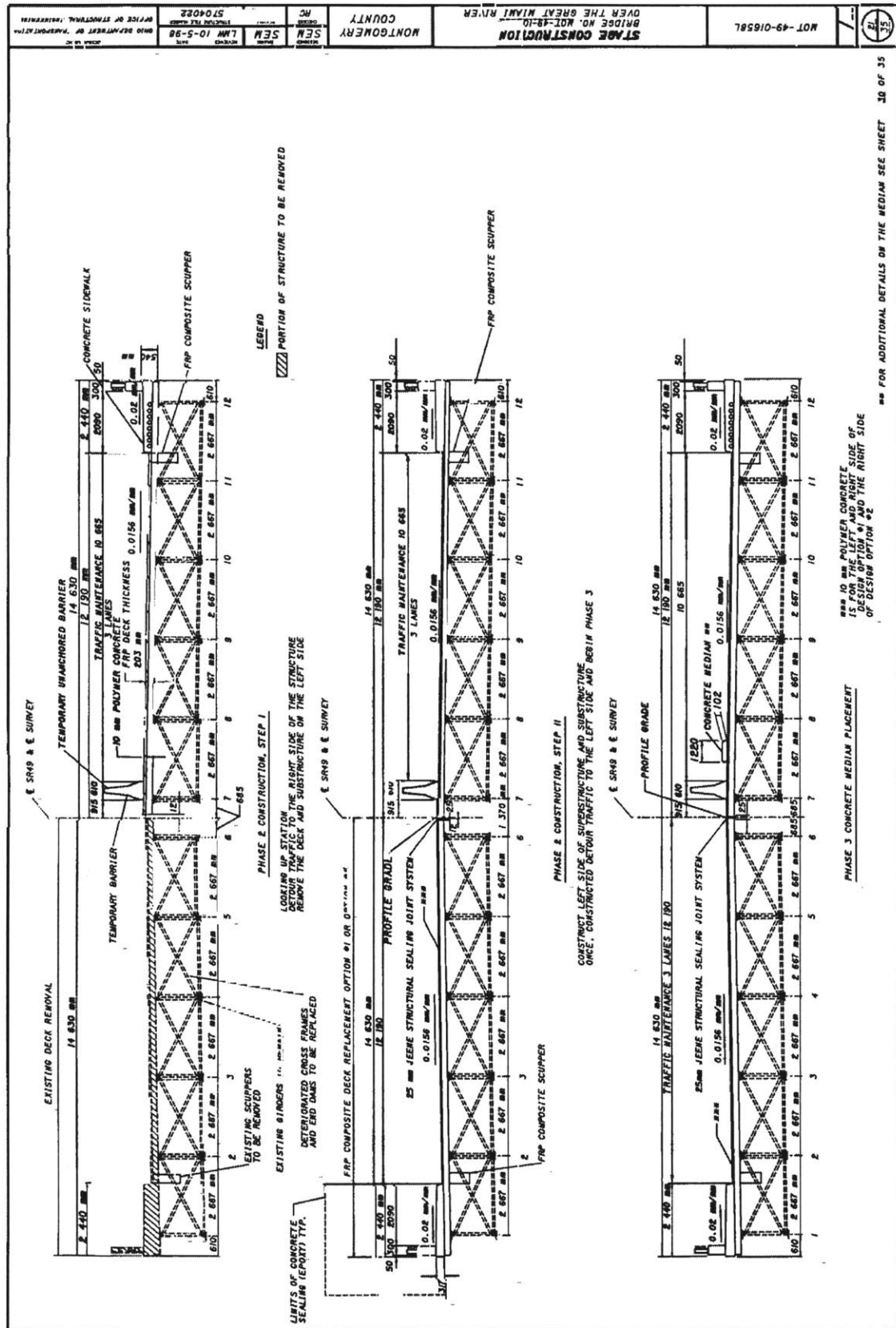
**APPROVED**  
 DATE \_\_\_\_\_ DIRECTOR, DEPARTMENT OF TRANSPORTATION

FEDERAL PROJECT NO. 17939  
 CONSTRUCTION PROJECT NO. 17939  
 RAILROAD INVOLVEMENT NONE  
 MONTGOMERY COUNTY MOT-49-1.634



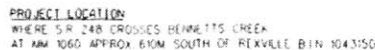






-

# Appendix B



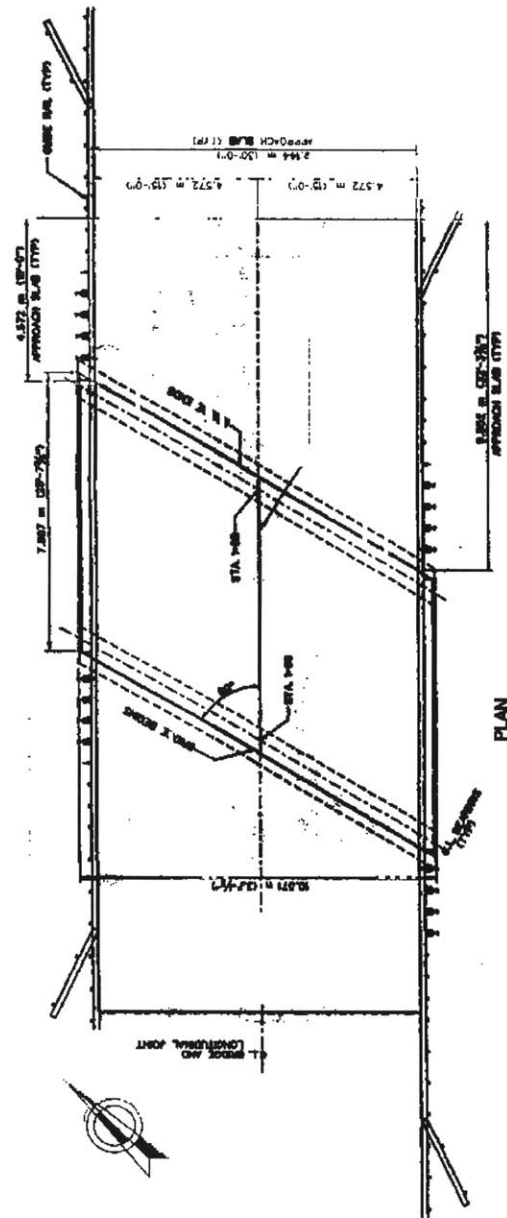
DOT WORK ORDER NUMBER: SH41A

ALL WORK CONTEMPLATED UNDER THIS CONTRACT IS TO BE COVERED BY  
AND IN CONFORMITY WITH THE STANDARD SPECIFICATIONS (METRIC UNITS)  
OF JANUARY 2, 1995, EXCEPT AS MODIFIED ON THESE PLANS.

S.R. 248 OVER BENNETTS CREEK			
B.I.N. 1043150 OVER BENNETTS CREEK			
TOWN OF WEST UNION			
STUEBEN COUNTY			
FED. ROAD REG. NO.	STATE	SHEET NO.	TOTAL SHEETS
1	M.V.	1	7
DOT WORK ORDER NO. 5841A			

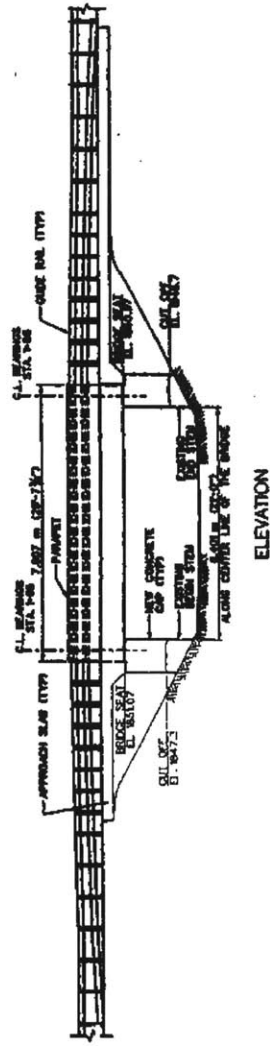
INDEX ON SHEET NO. 2

170	DATE	REV. NO.	BY	CHKD.	DATE
1	11/1	1	1	1	1
2	11/1	2	1	1	1
3	11/1	3	1	1	1
4	11/1	4	1	1	1
5	11/1	5	1	1	1
6	11/1	6	1	1	1
7	11/1	7	1	1	1



NOTES:

1. THE SCALE SHOWN ON THIS DRAWING IS A TRUE SCALE.
2. ALL DIMENSIONS ARE SHOWN IN METERS UNLESS NOTED OTHERWISE.
3. THE BRIDGE DECK SHALL BE CONSTRUCTED BY THE CONTRACTOR.



ELEVATION

*Vikar P. Singh* 12/24/1999

RT. 248 OVER BENNETTS CREEK  
GENERAL PLAN AND ELEVATION

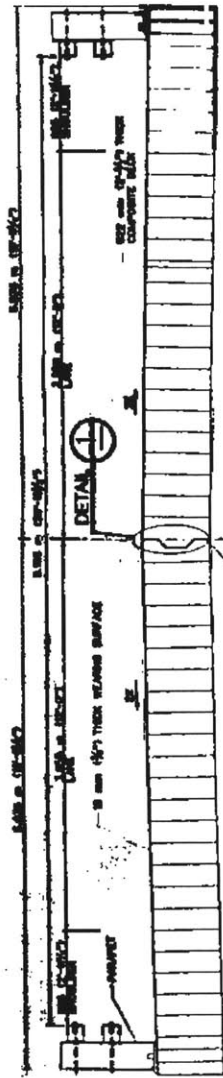
STATE OF NEW YORK  
DEPARTMENT OF TRANSPORTATION

DATE	SCALE	PROJECT NO.	DATE
11/1	1:125	11/1	11/1

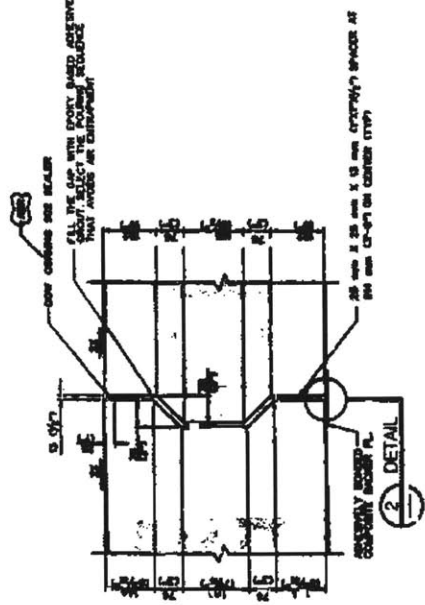


REV	NO.	DATE	BY	CHK	APP
1	1	10/1/99	WBS		
2	2	10/1/99	WBS		
3	3	10/1/99	WBS		
4	4	10/1/99	WBS		
5	5	10/1/99	WBS		
6	6	10/1/99	WBS		
7	7	10/1/99	WBS		

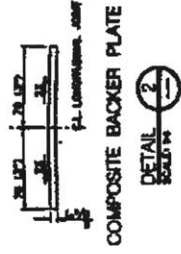
PROJECT	RT. 248 OVER BENNETTS CREEK
LOCATION	STATE OF NEW YORK
DESIGNER	DEPARTMENT OF TRANSPORTATION
DATE	10/1/99
SCALE	AS SHOWN
BY	WBS
CHK	
APP	



TYPICAL SECTION  
SCALE 1/4" = 1'-0"



DETAIL 1  
SCALE 1/4" = 1'-0"



DETAIL 2  
SCALE 1/4" = 1'-0"

NOTES:  
1. ALL DIMENSIONS SHOWN ON THIS DRAWING ARE IN FEET AND INCHES.  
2. ALL DIMENSIONS ARE SHOWN IN MILLIMETERS UNLESS OTHERWISE NOTED.

LEGEND:  
[Symbol] AS-BUILT REVISION

STATE OF NEW YORK  
DEPARTMENT OF TRANSPORTATION  
RT. 248 OVER BENNETTS CREEK  
TYPICAL SECTION AND DETAILS  
DATE 10/1/99  
SCALE AS SHOWN  
BY WBS  
CHK  
APP

# Appendix C

**Comparison of FRP Bridge Deck Panels**

<b>Manufacturer</b>	<b>Deck System</b>	<b>Manufacturing Process</b>	<b>Fiber</b>	<b>Matrix</b>	<b>Self-Weight (psf)</b>	<b>Depth (in)</b>	<b>Load Capacity</b>	<b>Deflection</b>
<b>3 TEX</b>	Fiber Reinforced Foam Sandwich	VARTM	E-glass		7	3.3	HS 25	L/500
<b>Hardcore Composites</b>	Honeycomb core	VARTM	E-glass	Vinyl-ester	20-35	8-28	HS 25	L/800
<b>Martin Marietta Composites</b>	Trapezoidal core	Pultrusion	E-glass	Polymer	18	8	HS 25	
<b>Kansas Structural Composites</b>	Honeycomb Sandwich	Hand Lay-up	Chopped strand mat	Polyester	20	0.090 (core)	HS 25	
<b>Creative Pultrusions</b>	Bonded double trapezoid	Pultrusion	E-glass	Vinyl-ester	22	8	HS 25	L/500
	& hexagonal sections							

# Appendix D

## REFERENCES

- Abbott, Steve – Contact at Maine Department of Transportation. Personal Interview. 30 Apr. 2001.
- Alampalli, Sreenivas et al. Design, Fabrication, Construction, and Testing of an FRP Superstructure. New York: Transportation Research and Development Bureau, New York State Department of Transportation, 2000.
- Apicella, F. “Research and Development Issues of Composite Resin Systems.” Conference Proceedings – Polymer Composites, Infrastructure Renewal and Economic Development, Parkersburg, West Virginia. 19-21 Apr. 1999.
- Bader, Michael G. “The Composites Market.” Comprehensive Composite Materials Volume 6. Ed. Anthony Kelly & Carl Zweben. Oxford, United Kingdom: Elsevier Science, 2000.
- Bettigole Neal. Bridge Decks. New York: ASCE Press, 1997.
- Blakely, Gerald L. Market Survey Report: Superdeck™ Fiber Reinforced Polymer Composite Bridge Deck. West Virginia University. Feb. 1998.
- Busel, John P. “Product Selection Guide: FRP Composite Products for Bridge Applications.” Harrison, New York: The Market Development Alliance, 2000.
- Cassity, Patrick A. “Fiber-reinforced Polymer Bridge Decks.” 8 (2000): 1-4
- Chawalwala, Arif. “Clever Cover-up.” www.bridgeweb.com 4<sup>th</sup> Quarter (2000): 59-60
- Chin, Joannie W. “Material Aspects of Fiber-Reinforced Polymer Composites in Infrastructure.” Gaithersburg, MD: Building and Fire Research Library, National Institute of Standards and Technology, Aug. 1996.
- Conway, Tim – Contact at the New York State Department of Transportation. Personal Interview. 23 Apr. 2001.
- Creese, R.C. “Overcoming Composite Cost Differentials by Life-Cycle Costing.” Conference Proceedings – Polymer Composites, Infrastructure Renewal and Economic Development, Parkersburg, West Virginia. 19-21 Apr. 1999.
- Daniel, Isaac M. and Ishai, Ori. Engineering Mechanics of Composite Materials. New York: Oxford University Press, 1994.
- Duthinh, Dat. “Connections of Fiber-Reinforced Polymer (FRP) Structural Members: A Review of the State of the Art.” Gaithersburg, MD: Building and Fire Research Library, National Institute of Standards and Technology, Aug. 2000.
- Duthinh, Dat. “Fiber Reinforced Polymer Composites in Construction.” Building and Fire Research Laboratory. 1998. BFRL. 12 May 2001.
- www.bfrl.nist.gov/860/ps98/FiberReinforcedPolymerCompositesinConstruction
- Ehlen, Mark A. “Life-Cycle Costs of Fiber-Reinforced-Polymer Bridge Decks.” Journal of Materials in Civil Engineering Aug. 1999: 224-230
- Ehlen, Mark A. and Marshall, Harold E. “The Economics of New Technology Materials: A Case Study of FRP Bridge Decking.” Gaithersburg, MD: Building and Fire Research Library, National Institute of Standards and Technology, July 1996.
- Fagrell, Brad – Contact at Ohio Department of Transportation. Personal Interview. 4 May 2001.
- Foster, Dean C. et al. “Design and Installation of Fiber-Reinforced Polymer Composite Bridge.” Journal of Composites for Construction. Feb. 2000: 33-37
- Gangarao, H.V.S. and Thippeswamy, H.K. “Advanced Polymer Composites for Transportation Infrastructure.” Conference Proceedings – Polymer Composites,

Infrastructure Renewal and Economic Development, Parkersburg, West Virginia. 19-21 Apr. 1999.

Gangarao, Hota – Professor at West Virginia University. Personal Interview. 4 May 2001.

GangaRao, Hota and Craigo, Carl A. “Fiber Reinforced Composite Bridge Decks in the USA.” Structural Engineering International. Apr. 1999: 286-288.

GangaRao, Hota et al. FRP Modular Bridge Deck Construction Issues. West Virginia University, Department of Civil and Environmental Engineering.

Hargrave, Martin W. “FHWA’s Applied Highway Infrastructure Research Program on Composite Materials.” FHWA’s Applied Highway Infrastructure Research Program on Composite Materials. Spring 1997. Federal Highway Administration 19 Mar. 2001 [www.tfhrc.gov/pubrds/spring97/compos.html](http://www.tfhrc.gov/pubrds/spring97/compos.html)

Hastak, Makarand and Halpin, Daniel W. “Assessment of Life-Cycle Benefit-Cost of Composites in Construction.” Journal of Composites for Construction. Aug. 2000: 103-111.

Henderson, Mark P. FRP Bridge Decks: The next step for Composites in Infrastructure. 2000. LJB Engineers. 14 May 2001. [www.ljbinc.com/ljb/ljbhomep.nsf](http://www.ljbinc.com/ljb/ljbhomep.nsf)

Hollaway, L.C. & Head, P.R. “Composite Materials and Structures in Civil Engineering.” Comprehensive Composite Materials Volume 6. Ed. Anthony Kelly & Carl Zweben. Oxford, United Kingdom: Elsevier Science, 2000.

Hooks, John M. “TEA-21 Promotes Innovative Materials and Technologies.” Bridge Builder Magazine. Apr.-May 1999:25-27.

Hooks, John – Contact at the Federal Highway Administration. Personal Interview. 23 Apr. 2001.

Koon, Terry B. – Contact at South Carolina Department of Transportation. “Re: FRP Bridge Decks.” E-mail to author. 27 Apr. 2001.

Lopez-Anido, Roberto et al. Design and Construction of Short-Span Bridges With Modular FRP Composite Deck. West Virginia University, Department of Civil and Environmental Engineering.

Lopez-Anido, Roberto et al. Fabrication and Installation of Modular FRP Composite Bridge Deck. West Virginia University, Department of Civil and Environmental Engineering.

Lopez-Anido, Roberto et al. Fatigue and Failure Evaluation of Modular FRP Composite Bridge Deck. West Virginia University, Department of Civil and Environmental Engineering.

Lopez-Anido, Roberto et al. “Evaluation of Polymer Concrete Overlay for FRP Composite Bridge Deck.” West Virginia University, Department of Civil and Environmental Engineering.

Lopez-Anido, Roberto. “Life-Cycle Cost Survey of Concrete Bridge Decks – A Benchmark for FRP Bridge Deck Replacement.” Proceedings from the Transportation Research Board 80<sup>th</sup> Annual Meeting. Washington D.C. 7 Jan. 2001.

McClaskey, C.R. “Competitive Products for Immediate Application.” Conference

O’Connor, Jerome – Contact at New York State Department of Transportation. Personal Interview. 27 Apr. 2001.

Nanni, Antonio. "New Structural Material –Fiber Reinforced Plastics." Emerging Construction Technologies. 24 Jun. 2000. Purdue University. 13 Feb. 2001. [www.new-technologies.org/ECT/Civil/frp.html](http://www.new-technologies.org/ECT/Civil/frp.html)>

Nettleton, Scott – Contact at Oregon Department of Transportation. "Re: FRP Bridge Decks." E-mail to author. 27 Apr. 2001.

Ohio Department of Transportation. Evaluation of Salem Avenue Bridge Deck Replacement Final Report. Ohio: Dec. 2000.

Plunkett, Jerry D. Fiber Reinforced Polymer Honeycomb Short Span Bridge for Rapid Installation. IDEA Program Transportation Research Board, June 1997.

Plunkett, Jerry – Contact at Kansas Structural Composites. Personal Interview. 26 Apr. 2001.

Proceedings from the Fourth International Bridge Engineering Conference, San Francisco, California. 28-30 Aug. 1995. Proceedings – Polymer Composites, Infrastructure Renewal and Economic Development, Parkersburg, West Virginia. 19-21 Apr. 1999.

Qiao, Pizhong. "A systematic analysis and design approach for single-span FRP deck/stringer bridges." Elsevier Composites Part B: Engineering, 2000:593-609.

Richards, Dan – Contact at Martin Marietta Composites. Personal Interview. 24 Apr. 2001.

Roberts, Jeff – Contact at the Maryland Department of Transportation. Personal Interview. 25 Apr. 2001.

Seible, Frieder, et al. "Advanced Composites for Bridge Infrastructure Renewal."

Tang, Benjamin & Podolny, Walter Jr. "A Successful Beginning for Fiber Reinforced Polymer (FRP) Composite Materials in Bridge Applications." FHWA Proceedings, International Conference on Corrosion and Rehabilitation of Reinforced Concrete Structures, Orlando, Florida Dec. 1998: 1-5

Shekar, V. "A Design Approach for FRP Composite Structural Shapes." Proceedings of Second Conference on Seismic Repair and Rehabilitation of Structures. Fullerton, CA, Mar 2000: 197-209.

Tang, Benjamin. "Fiber Reinforced Polymer Composites Applications in the USA." Bridge Technology. 28 Jan. 1997. U.S. DOT FHWA. 27 Apr. 2001. [www.fhwa.dot.gov/bridge/frp197.html](http://www.fhwa.dot.gov/bridge/frp197.html)

Troutman, Dustin – Contact at Creative Pultrusions. Personal Interview. 23 Apr. 2001.

Williams, Don – Contact at the West Virginia Department of Transportation. Personal Interview. 2 May 2001.

Yannotti, Arthur P. – Contact at New York State Transportation Research Bureau. Personal Interview. 23 Apr. 2001.